MANUFACTURER: PORTAC
MIN-ELL COMPANY, INC.
1689 BLUE JAY LANE
CHERRY HILL, NEW JERSEY 08003
TELEHPONE (609) 429-0421

PRODUCT LINE: CURRENT METER FLOW TUBES

DESCRIPTION:

PORTAC Flow Tube - The PORTAC Portable Sewer Conduit Flowmeter is a patented device (Figure A) that has been used successfully by New York City's Department of Water Resources Industrial Wastes Control Section for sewer flow measurement. The meter, shown in the plan view of Figure B, is designed to create full pipe flow in the sewer conduit, thus making the area of flow constant. (A self-damming flap gate, also shown in Figure B, is provided for this purpose.) The only other variable is velocity and this is measured with an OTT current (velocity) meter (shown installed in Figure C). The number of revolutions made by the meter's propeller are totalized on a digital counter. By applying the specific formula supplied with a particular system, flow totals can then be calculated.

As shown in Figure B, suspended deflectors, which are removable, are constructed immediately upstream of the current meter's propeller. This is done to reduce or eliminate the possibility of damage to the propeller by hard, fast-moving objects such as wood. The deflectors also generally redirect pliable suspended materials, normally encountered in sewer wastes, away from the area around the propeller's rotation.

Easily mounted on and suspended with a placement rod, the device can be installed (or removed) by only two sewer workers, regardless of manhole invert contours. Some of the hydraulic and physical advantages claimed for the PORTAC flowmeter are:

- Velocity of approach is not a factor if a high velocity propeller is used on the current meter;
- Sewer grade may be any value;
- The system is as good or better than a flume or weir in terms of ease of installation; the tube can also be easily sealed to ensure that all flow is being gaged;
- The system is unaffected by surcharging or submersion; and

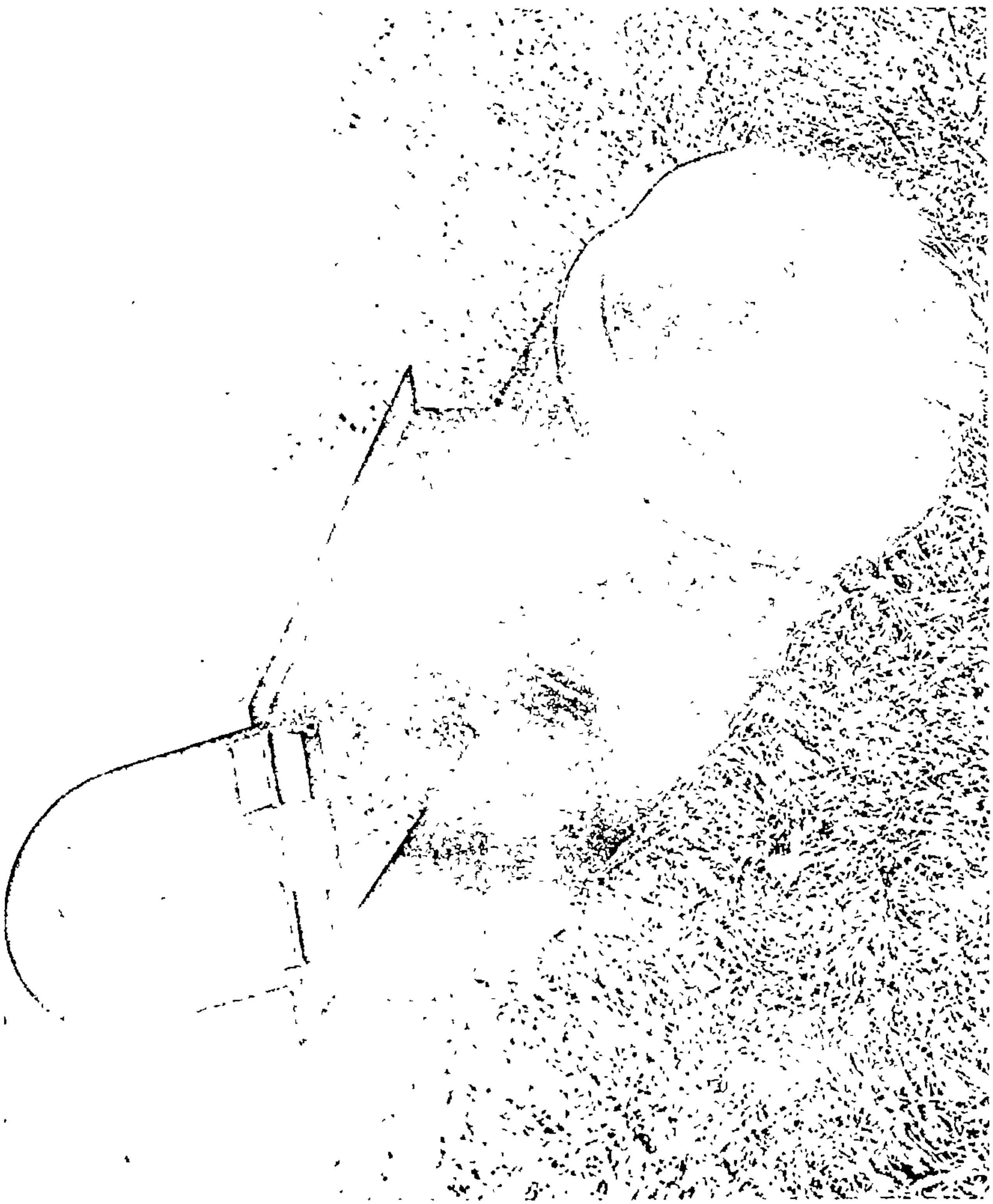


Figure A

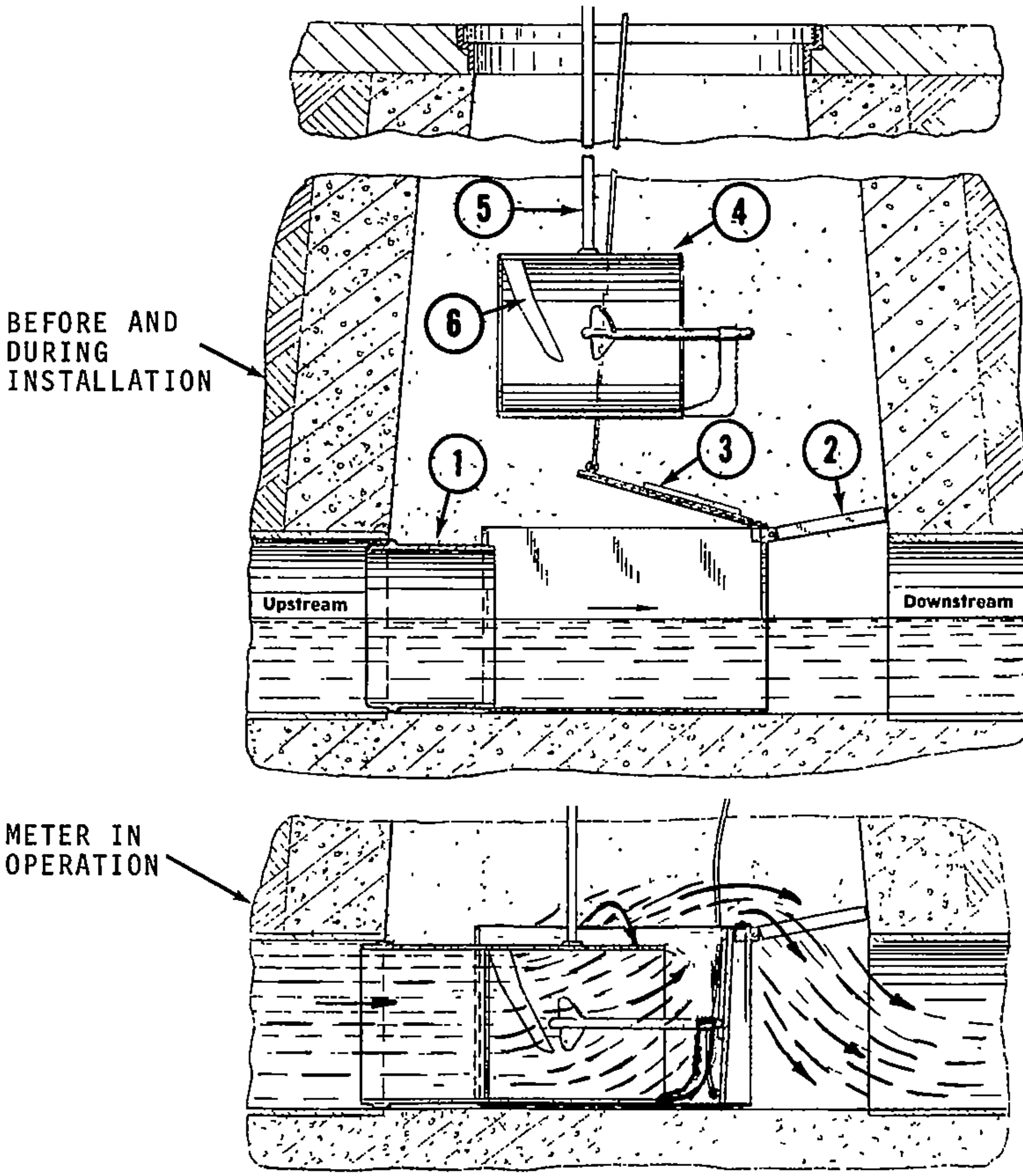

BEFORE AND DURING INSTALLATION
METER IN OPERATION
5
4
6
1
3
2
Upstream
Downstream

Figure B

Figure C

• The system does not need compressed air or AC power to operate, and thus is truly portable.

The flowmeter is fully adaptable for analog metering as well as strip chart recording. The standard metering package consists of: the flow tube; an OTT Model 10.002 current meter; and a three-digit, battery-operated counter model (F4). A five-digit counter (also battery operated), Model Z100, with other monitoring features* is also available, at additional cost. An optional current meter for use with PORTAC is the OTT Model 10.300 which has provisions for analogue strip recording.

Current Meters - In the OTT 10.002 standard unit shown in Figure D, signals are generated by means of a permanent magnet mounted on a worm sleeve which completes the circuit by way of an impulse device embodied in the meter following each revolution of the propeller. The device is

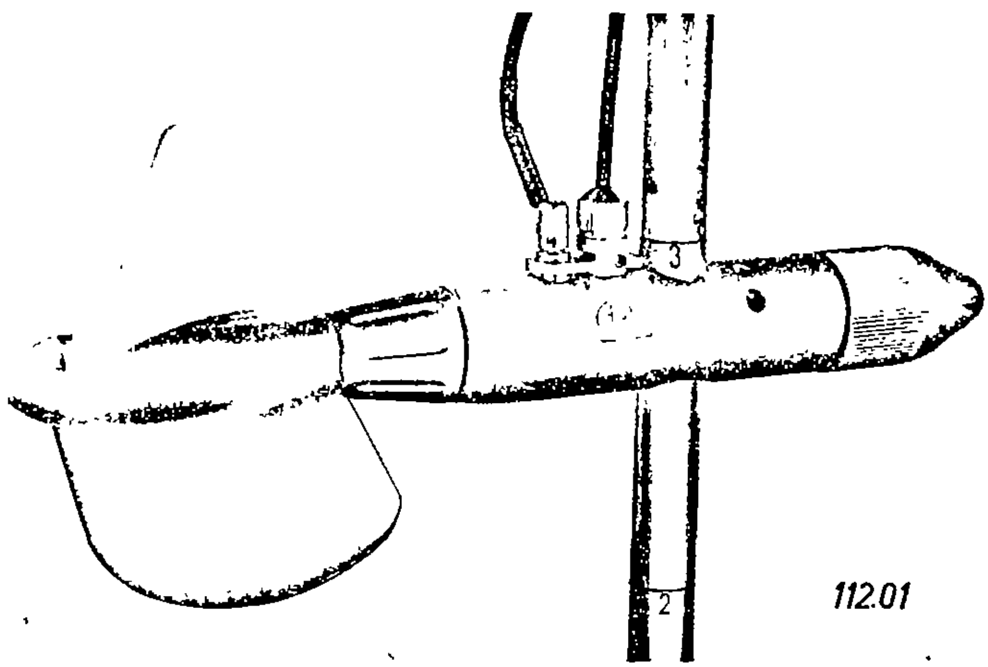


Figure D

* e.g., audible indication of input pulses by a loud buzzer.

largely free of restoring forces and may be said to operate virtually without power. The diameter and pitch of the propeller to be used is determined by the maximum flow velocity of the water to be encountered. A special table is provided to enable proper selection.

Counters - the three-digit F4 counter (type 12.000) counts a maximum of 10 pulses per second and is suited for operation with the OTT 10.002 (C31) current meter, which generates a signal pulse at each revolution of its propeller. Two 1.5-volt "D" size batteries serve as the power source and allow up to 48 hours of continuous operation without battery replacement. A stopwatch is used in conjunction with this instrument.

The Z100 five-digit counter is capable of measuring the length of pulse cycles from voltage-free transmitters (e.g., current meters), up to a maximum of 20 pulses per second. It is powered by six 1.5-volt single-cell batteries sufficient for about 30 hours of operation, assuming 8 hours of operation each day.

SPECIFICATIONS:

PORTAC Flowmeter (Less Current Meter and Counter)

Accuracy:	±3%, when velocity flow exceeds .027 m/s (0.09 fps)
Line Sizes:	15.2 to 45.7 cm (6 to 18 in.) Nominal I.D.

PRICES:

PORTAC (Less Current Meter and Counter)	\$815-\$915
PORTAC Complete with Current Meter and Counter	\$1150.00
Optional 5-Digit Counter (Z100)	\$950.00

COMMENTS:

Although this unit has been used in some sewers, it does not appear well suited for general storm or combined sewer applications, since it must suffer all the deficiencies of a current meter and is available only in small sizes.

MANUFACTURER: RAMAPO INSTRUMENT COMPANY
MACOPIN ROAD
BLOOMINGDALE, NEW JERSEY 07403
TELEPHONE (201) 838-2300

PRODUCT LINE: TARGET-TYPE FLOWMETERS, RECORDERS, INDICATORS

DESCRIPTION:

The RAMAPO Instrument Company manufactures a flow meter probe (the Mark V) which is reported to be widely used for measuring industrial wastewater flows. The company also offers several other flowmeters, including the newly-developed Mark VI target flowmeters, and a variety of recording and indicating devices.

Mark V Flowmeter Probe - This device will measure most process fluids in pipelines. This is done by installing a flanged fitting into an existing pipeline (see Figure A). The strain gage force sensing element of this device has no bearings or other rotating parts. The electrical signal can be transmitted to remote locations or used for indicating, recording, controlling, and totalizing. The Mark V Flowmeter measures flow in terms of the dynamic forces acting on a fixed body in the flow stream. Bonded strain gages in a bridge circuit outside the fluid stream and shielded by stainless steel, translate this force into an electrical output proportional to the flow rate squared.

A modification of the standard Mark V Flowmeter Probe, a retractable probe, is also available for pipeline applications. This particular device can be installed in or removed from pressurized systems without causing a shutdown. The probe can be moved from line to line - even for widely varying line sizes - for sampling or spot checking of flows. Materials and specifications are generally the same as those for the standard probe.

Other Flowmeters - Less suitable for effluent flow measurements is the Mark V flowmeter for tube end and pipe connection applications. They are usable with slurries and some types of abrasive fluids, however. Accuracy is reported to exceed ±0.5 percent in flow ranges of approximately 10:1. Line sizes available are from 1.3 to 15.2 cm (0.5 to 6 in.) with any standard end fitting, with special sizes supplied upon request.

The Mark VI Target Flowmeter is a new product which has been developed for measuring flows of dirty liquids, slurries, etc. This flowmeter has no moving parts and no cavities to collect particles or entrap materials that can harden. Available in a wide variety of line sizes and configurations, it has operational performance characteristics similar to the Ramapo Mark V Target Flowmeter.

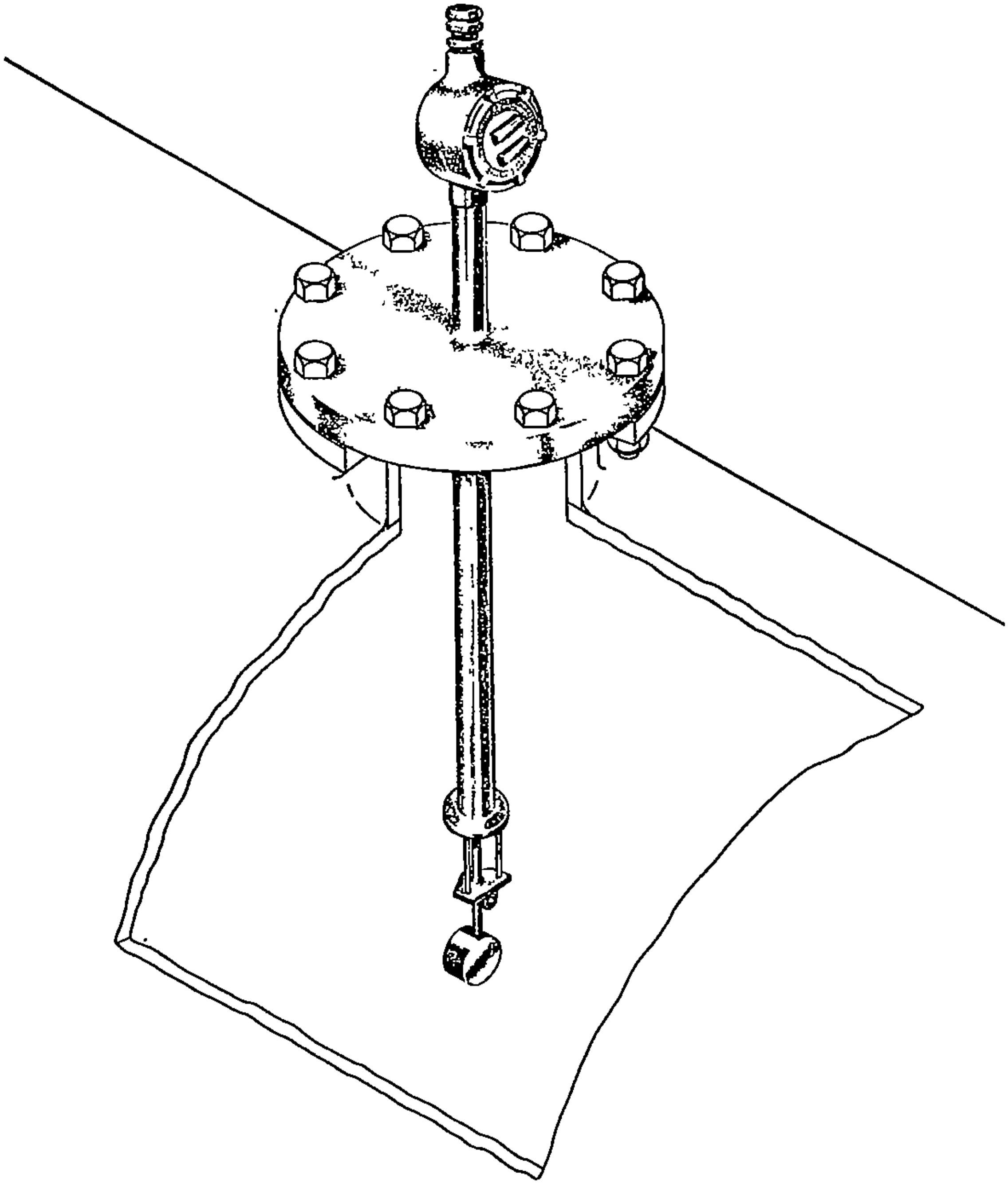


Figure A

Secondary Flowmeasuring Devices - Ramapo markets several recently-developed recorders and digital flowmeters compatible with the Mark V and Mark VI.

One type records flow on an inkless, 5.1 cm (2 in.) wide chart. Signals accepted are typically 0-1 volt or 4-20 mA. The scale and chart use square root ruling so that the flow rate signals originating at target meters, orifices, and other differential pressure devices can be read directly in percent of flow. One chart lasts 30 days. Absolute accuracy is ±2 percent.

Digital-reading flow indicators, with BCD output if desired, are available for reading in engineering units such as GPM, CFM, and ℓ/s. Depending upon the application, the display can present readings to a maximum of 1999, 3999, or 19999.

SPECIFICATIONS:

Line Size*:	10.16 to 152.4 cm (4 to 60 in.)
Calibration*:	±1%; 2%
Accuracy:	±1% full flow (Bi-directional)
Range:	Any 10:1 range up to a line velocity of 4.57 m/s (15 fps) maximum
Materials*:	Stainless steel sensing element; Mounting flange as specified
Pressure Loss*:	Usually less than 10 cm (4 in.) of water
Input:	5 to 10 VDC
Output:	Up to 20 mVDC maximum or 2.0 mVDC input for full range flow rate. Semiconductor gages available for higher output
Connections*:	Terminal strip in explosion-proof enclosure, or submersion-proof head and cable

* Mark V Flowmeter Probe Only.

PRICES:

Mark V Flowmeter Probes (Standard)

$745 to $1,195 (2% Calibration)

$960 to $2,300 (1% Calibration)

COMMENTS:

Although useful for some types of wastewater flows, these target-type devices do not appear suitable for extended use in the storm or combined sewer application. Their limited range and vulnerability to impact by debris make all but attended, short-time use appear unfeasible.

MANUFACTURER: ROBERTSHAW CONTROLS COMPANY
P.O. BOX 3523
KNOXVILLE, TENNESSEE 37917
TELEPHONE (615) 546-0524

PRODUCT LINE: PARSHALL FLUMES; CAPACITANCE TRANSMITTERS; RECORDERS; INTEGRATORS; TOTALIZERS; ETC.

DESCRIPTION:

Robertshaw markets a variety of analytical and measurement devices, many of which are designed for use with water and wastewater instrument systems. Typical of these is the Series F-Flume Flow Measurement System, which incorporates a circular chart recorder with optional integrator, or a panel-mounted recorder/totalizer.

Flume - The system (Figure A) utilizes as its primary measurement device a Parshall "Free Flow" flume, constructed of polyester reinforced fiberglass with Sanitary Satin finish. The flume is equipped with a molded-in capacitance sensing probe that is characterized to provide a linear output signal directly proportional to flow. The flume is a one-piece, completely self-supporting unit ready for installation in concrete. A ruggedized model may be installed in conduits above the ground. The flume and its associated instrumentation are suitable for many open channel applications.

Transmitter - A capacitance sensing transmitter (Figure A) can be installed directly on the flume probe (Model 157), or mounted in a location remote from the flume. No stilling well is required. Because there are no floats, moving parts, or mechanical linkages, performance is enhanced.

Flow Recorders and Integration/Totalization - Flow recording and integrating/totalization may be provided with the Series F system using the Model 241 circular chart recorder with optional integrator, or the Model 225/534 recorder/totalizer for front panel flush mounting.

The Model 241 electronic circular chart recorder is available in single or two pen versions in a weathertight enclosure for surface or panel mounting. Optional features include built-in integrator-totalizer and/or square-root extractors.

The Model 534 Integrator-Totalizer provides continuous integration and totalization of process signals with respect to time. Ratio adjustment is by means of a long-scale, thumbwheel dial, calibrated for linear or square-root signals. A vertical scale meter displays input/output signals.

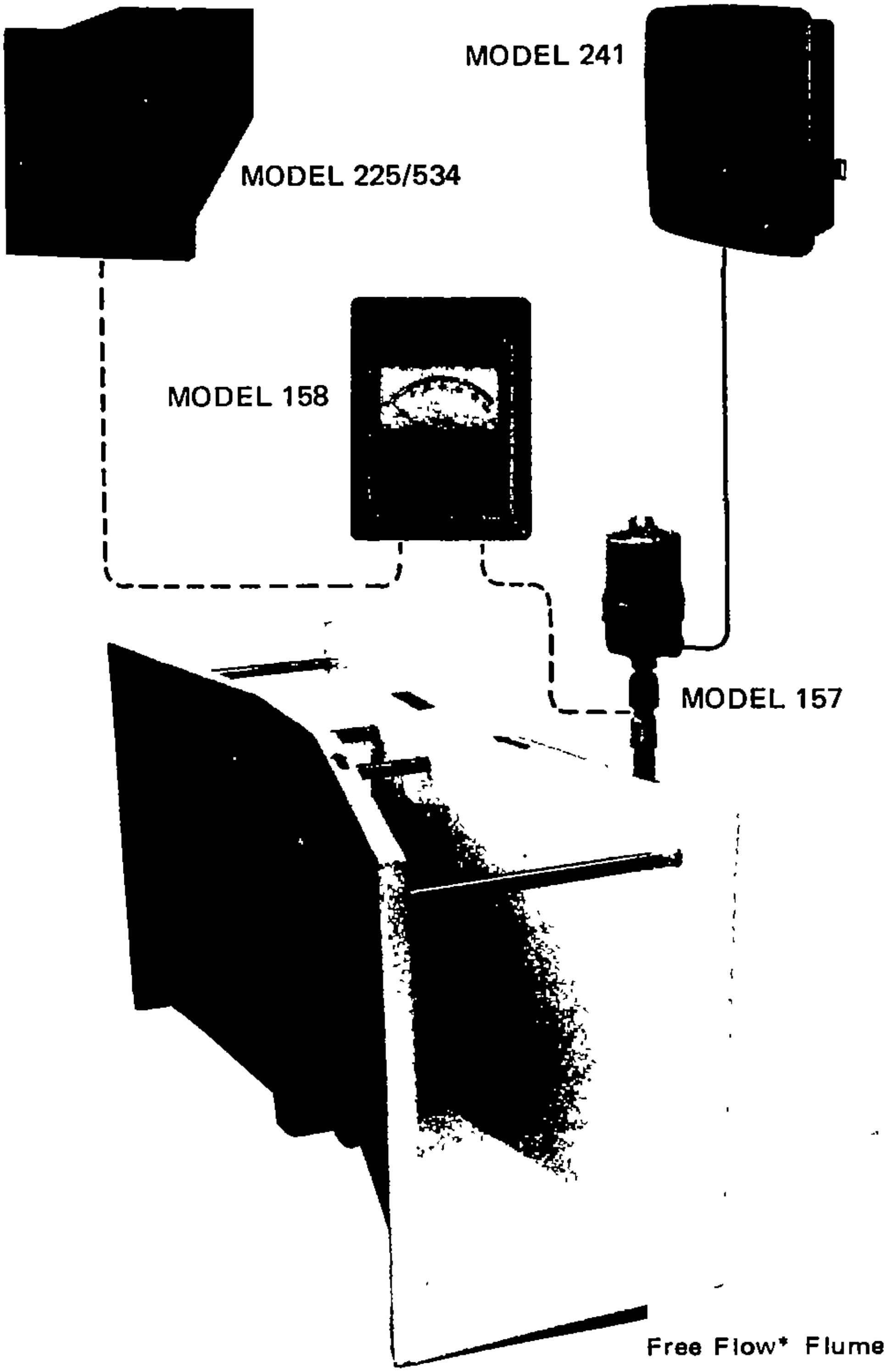


Figure A

The Models 157/158 Level Tels (transmitters) are capacitance sensing instruments producing standard output current signals and are used for continuous level indication or control.

SPECIFICATIONS:

<u>Model 157/158 Transmitters</u>

Output Signal:	1 to 5, 4 to 20, 10 to 50 mADC
Linearity:	±0.25% of full scale
Repeatability:	±0.1% of full scale
Power:	117/230 VAC or 26 VDC

<u>Model 241 Circular Recorder</u>

Input Signals:	1 to 5, 4 to 20, 10 to 50 mADC
Accuracy:	±1.0% of full scale
Repeatability:	±0.2% of full scale
Pen Response:	2 to 20 sec., adjustable
Power:	117/230 VAC, 50-60 Hz

<u>Model 534 Integrator-Totalizer</u>

Input Signals:	1 to 5, 4 to 20, 10 to 50 mADC
Accuracy:	±0.375% of full scale
Repeatability:	±0.1% of full scale
Count Rate:	1000 to 20,000 CPH
Power:	117/230 VAC or 26 VDC

PRICES:

Not available at time of writing.

COMMENTS:

The capacitance gage molded into the Parshall flume offers advantages for some applications. Parshall flumes were thoroughly discussed in Section VI and will not be commented on further here.

MANUFACTURER: SARATOGA SYSTEMS, INC.
10601 SOUTH SARATOGA-SUNNYVALE ROAD
CUPERTINO, CALIFORNIA 95014
TELEPHONE (408) 257-7120

PRODUCT LINE: ULTRASONIC FLOWMETERS

DESCRIPTION:

Saratoga Systems Inc., under licensing agreement with Lockheed Aircraft Corporation, has patented and is producing the "ULTRAMETER", a frequency difference type "ultrasonic" flowmeter which combines sonar and advanced micro-electronic concepts to measure the flow of any medium capable of providing a uniform flow profile and propagation sound waves in an undistorted manner. This device has a number of applications in the wastewater field.

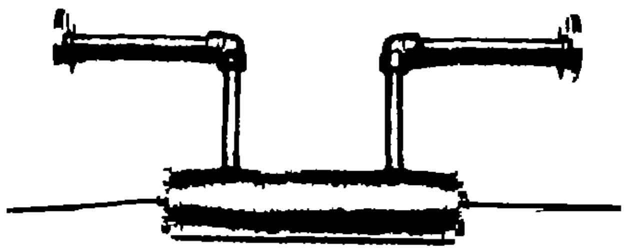
The Model 201 Ultrameter provides either an analog output, or a digital output that is directly proportional to the average speed of a fluid flowing in a pipeline and which can be related to volume flow rate. The measurement system, which employs a pair of non-intrusive diagonally-opposed transducers mounted directly on the pipe itself (see Figure A), is independent of the sound speed in the fluid as well as fluid density, composition, viscosity, and temperature.

Sound "bursts" are propagated alternately in opposite directions between the two transistors. Because the upstream signal is delayed and the downstream signal is speeded up by the moving fluid, the alternate bursts yield a frequency difference which is a highly accurate measurement of the flow (to 0.2%). The measurement also provides linearity even at very low flow rates.

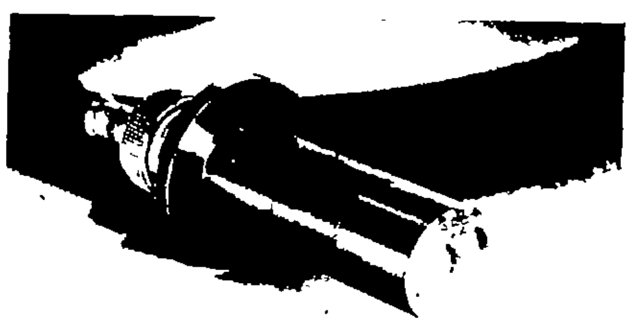
Analog current or digital pulse trains are both simultaneously available from the "ULTRAMETER", and can feed directly to recording and computing equipment. These data signals can be scaled to any desired output dimensions, such as GPM or cubic feet per minute.

Features include:

- Bi-directional flow measurement capability
- No head loss or obstruction to flow
- No moving parts
- No recalibration after initial factory or inplace calibration



Axial flow section, useful for pipe sizes from ⅛″ inside diameter to 3″ inside diameter.



Ultrameter transducer receives and emits sound waves.

Figure A

100 percent Solid State electronics including replaceable, interchangeable modules and an automatic failure alarm system

The flowmeter may be employed in pipelines ranging from 7.62 cm (3 in.) diameter pipes to open channels.

SPECIFICATIONS:

A typical 9 cm (4 in.) meter flowing 757 ℓ/m (200 gpm) has the following performance and operational characteristics:

Accuracy:	±0.5% (full scale error with calibration)
Resolution:	±0.2% (full scale)
Ranges:	
Upper Flow Limit	100 x Full Scale
Lower Flow Limit	0.1 x Full Scale
Data Format Options:	
Digital	Positive true logic, TTL compatible pulse train proportional to flow.
Analog	0.5% D/A conversion Current Source 0-1, 4-20 or 10-50 mA (Full Scale) Voltage Source ±1 or 0-5 volts (Full Scale)
Power:	117 VAC, 50-60 Hz @ 1 amp
Size:	
Standard Meter Bodies w/ Transducers	0.32 to 46 cm (0.125 to 18 in.)
Weld-on Transducer Installations	10 cm (4 in.) up
Weight:	
Instrument Package	27.2 kg (60 lbs)
Transducers (depending on installation)	42.5 g to 9 kg (1.5 oz to 20 lbs)

PRICE:

Typical price in 20 cm (8 in.) size with remote read-out is $3,680.

COMMENTS:

A large quantity of particulate matter (as can be found in raw or untreated sewage) or heavy concentration of air bubbles can affect the system, although it is reported that up to 50 percent concentrations of solids have been handled. These factors have to be determined in advance consultations with the manufacturer.

There is no restriction on the transducers, but the line has to be full of liquid. The electronic control box can be mounted in any orientation except upside down, but must be within 15m (50 ft) of the transducers. This distance can be extended to 30m (100 ft) under special circumstances.

Overall accuracy of this ultrasonic device depends to a certain degree on the stability and definition of the fluid velocity within the meter path. In some circumstances (e.g., in large diameter pipes and open channels), the flow velocity profile is unstable. Several statistical averaging techniques, such as the Gaussian integration method, can be used with the "ULTRAMETER" to improve accuracy. However, these techniques are complex and involve additional expense.

MANUFACTURER: SCARPA LABORATORIES, INC.
46 LIBERTY STREET, BRAINY BORO STATION
METUCHIN, NEW JERSEY 08840
TELEPHONE (201) 549-4260

PRODUCT LINE: ACTIVE AND PASSIVE ACOUSTIC FLOWMETERS

DESCRIPTION:

Scarpa Laboratories currently manufactures a line of ultrasonic flowmetering and sensing instruments which cover a wide range of liquid and gas applications. Those meters appearing to be best suited for wastewater applications are the non-contacting, clamp-on passive acoustic SFM/SFS Series (2, 3, 4, 5) meters (these are the least expensive) and several more expensive models (e.g., Type II SDL-10, Type IV SDL-8, etc.) that utilize the time difference principle and digital computer technology.

Passive Flowmeters - These clamp-on flow indicators utilize the acoustic emission principal and appear to be usable for liquids, solids, gases, and slurries. All models in this series read relative velocity for liquids and gases and relative mass flow for slurries and solids. The "SCARPA-SONIC" device responds, through a microphone, to broadband noise generated by the moving medium - noises which range from the audible to the high ultrasonic spectrum. Filters are provided to eliminate spurious sounds from sources other than the flowing material. In the cases of liquids and gases, the signal produced is an analog output which is a function of flow velocity; for slurries and powders, it is a function of mass velocity. The sensor element clamps or bonds to the outside of the pipe wall, and the manufacturer states that their best sensing locations are at elbows or flanges. It is further recommended that they should be located at least 3m (10 ft) away, and preferably as far away as possible, from pumps or compressors as they may introduce spurious signals that could pass through the receiver band-pass filters. Very low flow velocities (e.g., slurries) may be sensed by imposing some form of "flow spoiler" in the stream such as an orifice, pipe constrictions, or even any small projection which does not have to have rotational symmetry.

This meter may be used for any pipe size, ranging from 0.31 cm (1/8 in.) O.D. copper tubing to 305 cm (120 in.) or larger pipe diameters. Millivolt, milliampere, and relay contact closure outputs are available. The meter must be calibrated at the site of installation.

Active Flowmeters - The Scarpa active ultrasonic liquid (called "doppler") flowmeter indicates flow by means of two transducers either clamped on the opposite outside walls or inserted through the walls of any pipe size from 7.61 to 152.4 cm (3 to 60 in.). The instrument transmits and receives ultrasonic signals through the pipe wall and across the flow stream at an angle to the flow. The actual measurement is of velocity and is transformed to volumetric flow by means of conversion tables that correct for pipe wall thickness and internal diameter. Units for a specific pipe size can be factory calibrated to read directly in GPM.

Applications range from non-intrusive flow surveys to flow measurement and control where the non-liquid contact feature is essential. The electronics are housed in an industrial grade Nema 4 gasketed box with hinged door.

The doppler type units all employ digital computer technology in processing the information obtained from the ultrasonic "front end." BCD or binary outputs can be provided, as well as 0 to 10 volts, 4 to 20 mA or 10 to 50 mA analog outputs. Digital flow rate displays are also available as standard equipment.

All transducers are metal encased and transmit and receive through resonant metal "windows." As such they can withstand high pressures and most corrosive environments. Materials of construction may be aluminum, titanium, monel or stainless steel. Explosion proof housings are available at additional cost.

SPECIFICATIONS:

Series SF-( ) Flowmeters

Range:	0.3-1.5 m/s (1-5 fps) to sonic velocities*
Accuracy:	Calibrated in place
Reproducibility:	±1%
Power:	117 VAC, 1/10 Amp, 50/60 Hz 9-V Battery Power available some models
Temperature Range:	-40° to + 150°C (Sensor) -40° to + 80°C (Receiver)

Ultrasonic Liquid Doppler Flowmeters (Typical)

Range: (Flow velocity)	0.3 to > 9 m/s (1 to > 30 fps)
Accuracy:	±2%

* 0-100 μA meter indicates relative flow velocity. May be calibrated on site to indicate actual flow rate.

Repeatability ±2%

PRICES:

SF- Series Flowmeters

SFS-2-RPS	Ultrasonic Clamp-On Flow Switch, with Regulated Power Supply.	$181.50
SFM-3-BP	Ultrasonic Clamp-On Flow Meter, Battery Powered Batteries - $2.75 each extra (2 required)	$330.00
SFM-4-RPS	Ultrasonic Clamp-On Flow Meter, with Regulated Power Supply.	$341.00
SFSM-5-RPS	Flow Switch, Flow Meter Combination with Regulated Power Supply	$467.50
TSL-2-( )	Clamp-On Flow Sensors-Transmitters (Note: At least one TSL-2-( ) sensor is required with each receiver)	$ 93.50 to $165.00

Ultrasonic Liquid Doppler Flowmeters

Type SDL-10	(Clamp on unit)	$3,500-$5,000
Type SDL-8	("Wetted" sensors)	$3,500-$10,000

COMMENTS:

Scarpa offers the only passive acoustic flowmeters on the market today, but little is known about their use in a storm or combined sewer application.

MANUFACTURER: SIGMAMOTOR, INC.
14 ELIZABETH STREET
MIDDLEPORT, NEW YORK 14105
TELEPHONE (716) 735-3616

PRODUCT LINE: BUBBLER-TYPE SECONDARY FLOWMETER

DESCRIPTION:

Sigmamotor has recently introduced their LMS-400 battery operated, open channel flowmeter. It is a bubbler-type secondary device in which a pressure transducer senses the back-pressure experienced by an inert gas which is bubbled at a constant flow rate through a tube anchored at an appropriate point with respect to the primary device (weir, flume, etc.). The flow depth is thus determined and electronically integrated into the appropriate flow equation. Appropriate numeric values for the rest of the flow equation are set with two dials on the front of the meter.

The device appears to be extremely simple to set up and put into operation. It can operate up to 122m (400 ft) from the measurement site. This unit, which is claimed to be one of the smallest and most accurate flowmeters available, is equipped with a 31-day pressure sensitive strip chart recorder for a continuous record of flow rate and a six digit totalizer reading in gallons to indicate total flow over time. Besides the flow rate readouts in CFS or MGD, the LMS-400 can be set to simply give depth readouts in either feet or inches. It is also designed to supply a flow-proportional signal for an automatic sampler and will indicate at what time each individual aliquot was taken.

SPECIFICATIONS:

Accuracy:	±2% from the theory curve of the primary device
Power:	AC units, 115V DC units, 12V Lead Acid Type Battery
Battery Life:	30 Amp-Hour - 10 days 15 Amp-Hour - 5 days
Bubbler Cylinders:	0.9 kg (2 lb) Freon R-12 gas cylinders (two) last for approximately 3 to 4 weeks
Dimensions:	34.3x36.8x25.4 cm (13.5x14.5x10 in.)
Weight:	15.9 kg (35 lb) with 30 Amp-Hour Battery 11.8 kg (26 lb) with 15 Amp-Hour Battery 8.2 kg (18 lb) AC model

PRICES: $1,750 for AC-DC Unit

COMMENTS:

This small, versatile unit appears to be well suited, in conjunction with appropriate primary devices (linear, 3/2 or 5/2 power), for many wastewater flow surveys. Its complete portability makes it especially attractive for such use. Wide range requirements could pose a problem; although the unit has four range settings, they must be set manually.

MANUFACTURER: SINGER-AMERICAN METER DIVISION
13500 PHILMONT AVENUE
PHILADELPHIA, PENNSYLVANIA 19116
TELEPHONE (215) 673-2100

PRODUCT LINE: PARSHALL AND PALMER-BOWLUS FLUMES; LIQUID LEVEL GAGES

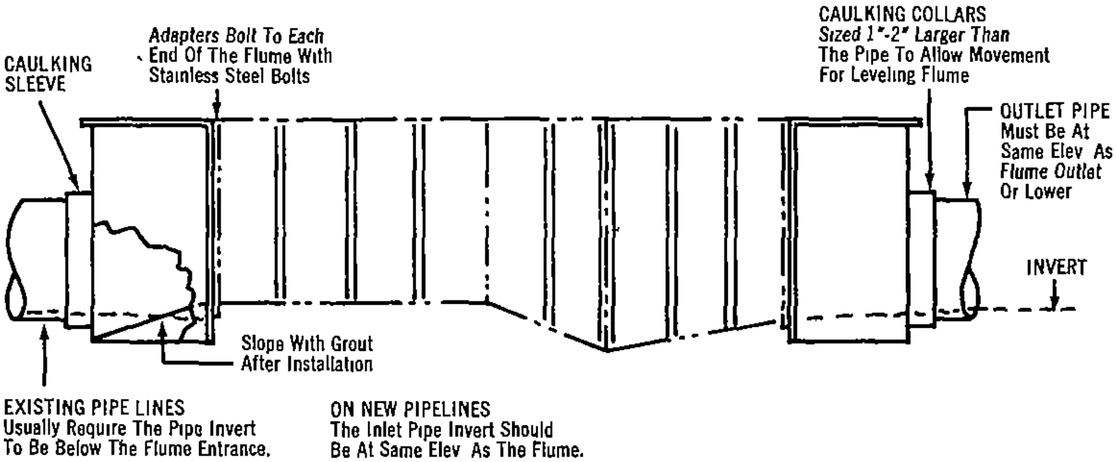
DESCRIPTION:

The American Meter Division of Singer offers Parshall flumes in sizes from 7.6 to 30.5 cm (3 to 12 in.) as standard and up to 2.4m (8 ft) on special order. The flumes are heavily ribbed for free-standing installations and may also be used as liners in concrete. They are fabricated in one piece from polyester plastic resin, reinforced by glass mat not less than 30 percent by weight, and have a smooth white surface. A connection is available on either side for a bubbler pipe, and a head gage is molded into the side of the flume. For installation in pipelines, American also offers Parshall flume end adaptors to make the transition from round pipe to rectangular flume and back to round (Figure A). Short-section flumes (i.e., no diverging section), are available for use where space is restricted and the additional head loss is tolerable.

The Palmer-Bowlus flumes offered by American feature a trapezoidal section with a flat bottom. Recommended installation techniques include grouting or adhesive bonding. They are also molded from fiberglass-reinforced isophthalic polyester resin with a white gel coat interior surface. The outside surface has clips for anchoring to concrete. The flume includes a built-in stainless steel bubbler tube.

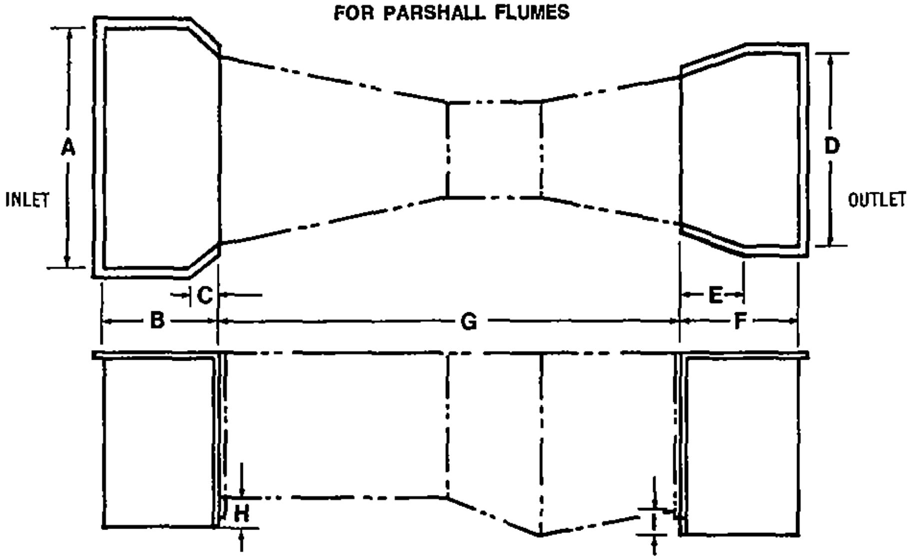
American offers a number of secondary elements (Figure B) for use with V-notch weirs, rectangular weirs, Parshall flumes, and Palmer-Bowlus flumes. Spring-wound, battery, or electrical (110 VAC) chart drive speeds can be either 24 hours or 7 days per revolution. Integrating instruments use electrical drive charts.

The American bubbler tube level system utilizes an air pump to pressurize a capsular pressure element. A tee is incorporated in the line leading to the capsular pressure element to bleed off a continuous flow of air (back pressure at the capsular pressure element) to the dip tube. The dip tube is open at one end and submerged, for example in a weir with the open end on a plane with the bottom of the weir notch. The air escaping from the open end of the dip tube produces bubbles (air pump is adjusted to produce approximately 30 to 90 bubbles per minute); thus, the air pressure in the dip tube corresponds to the hydraulic head of the liquid. As the liquid head varies, the pressure in the tube changes. This tube pressure is proportional to the pressure variation at the capsular pressure element. Here the movement of the capsular pressure element is transmitted to an integrating stylus and recording pen arm which accurately records a pattern of liquid flow. The integrating instrument totalizes the actual volume measured. The integrating mechanism is a rotating cylindrical cam with a surface corresponding to the weir notch characteristic. Depending upon the position of the pressure stylus, the cam actuates the counter drive for a portion of each revolution. Since all functions are performed by special gearing, there are no clutches to cause backlash or slippage.



STANDARD INLET AND OUTLET ADAPTERS

FOR PARSHALL FLUMES



End Connections, such as caulking collars, are not shown as size and type may vary.

FLUME SIZE	A	B	C	D	E	F	G	H	I
3"	1'-6"	12"	9"	1'-6"	9"	12"	3'-0"	5"	4"
6"	2'-0"	1'-6"	7"	2'-0"	7"	1'-6"	5'-0"	6"	3"
9"	2'-8"	1'-9"	8"	2'-0"	8"	1'-9"	5'-4"	6"	4"
12"	3'-9"	2'-0"	10"	2'-9"	8"	2'-0"	9'-4⅜"	7"	4"
18"	4'-4"	2'-0"	10"	3'-4"	8"	2'-0"	9'-7⅞"	8"	5"
24"	5'-0"	2'-6"	7"	4'-8"	1'-4"	2'-6"	9'-10⅞"	8"	5"

Figure A

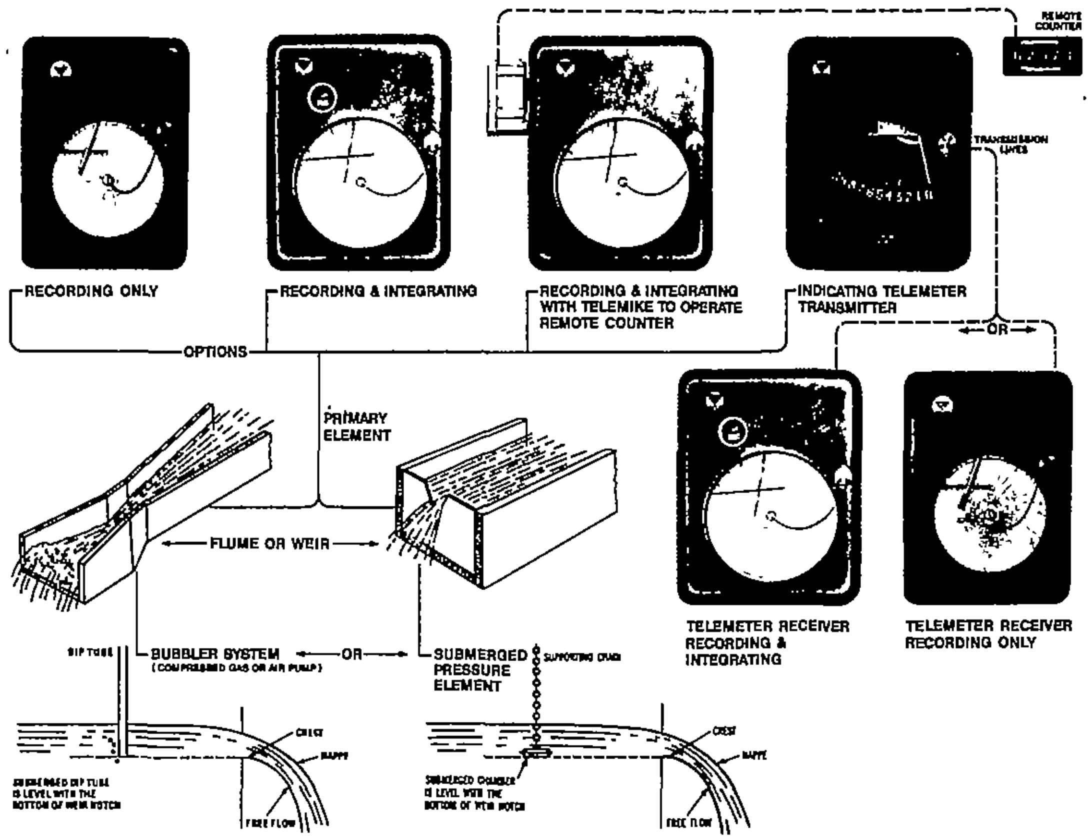

REMOTE COUNTER
RECORDING ONLY
RECORDING & INTEGRATING
RECORDING & INTEGRATING WITH TELEMIKE TO OPERATE REMOTE COUNTER
INDICATING TELEMETER TRANSMITTER
TRANSMISSION LINES
OPTIONS
OR
PRIMARY ELEMENT
FLUME OR WEIR
TELEMETER RECEIVER RECORDING & INTEGRATING
TELEMETER RECEIVER RECORDING ONLY
BUBBLER SYSTEM
OR
SUBMERGED PRESSURE ELEMENT
CREST
FREE FLOW

Figure B

MANUFACTURER: SPARLING DIVISION
ENVIRONTECH CORPORATION
4097 NO. TEMPLE CITY BLVD.
EL MONTE, CALIFORNIA 91731
TELEPHONE (213) 444-0571

PRODUCT LINE: PROPELLER FLOWMETERS; TRANSMITTERS, RECORDERS, AND INDICATORS/TOTALIZERS

DESCRIPTION:

Sparling Manufactures a variety of propeller-type meters, electromechanical devices and controls, solid state instruments, and telemetering equipment. Some of these are suitable, or are potentially acceptable, for some wastewater and/or sewer flow applications. Of particular interest are the Series 100 meters (Masterflow wastewater meters) and a variety of electrical flow rate transmitters for use with flumes or weirs or for mounting on meterheads to operate remote recorders, indicators, and/or totalizers.

Sparling offers two styles of wastewater meters - the flanged Masterflow tube type and the Masterflow Open Flow type (see Figure A). For both models, application in measuring waste flows is recommended only after primary treatment, including waste or return activated sludge. These meters are not recommended for raw sewage or primary sludge flows. Therefore they will not be described further.

Secondary Measurement Devices - Secondary devices offered by Sparling include the following:

- Pulse-Rate Transmitters - These designs utilize an optical pulse-rate generator to provide a 0 to 20 PPS signal directly proportional to flow rate.

- Electronic Transmitters - Measure and transmit level, pressure, or other variables. Output signal accuracy is ±1%. Pulse frequency, DC voltage, or current output modes.

- Miniature Strip-Chart Recorders - Indicate and continuously record flow, pressure, level, or other variables. Can accommodate solid state or relay-contact output switches for alarm, status indication, etc.

- Circular-Chart Recorders - Feature 30.4 cm (12 in.) linear charts designed for either 24-hour or 7-day recording; 25.4 cm (10 in.) indicator scale; and six-digit direct-reading totalizer.

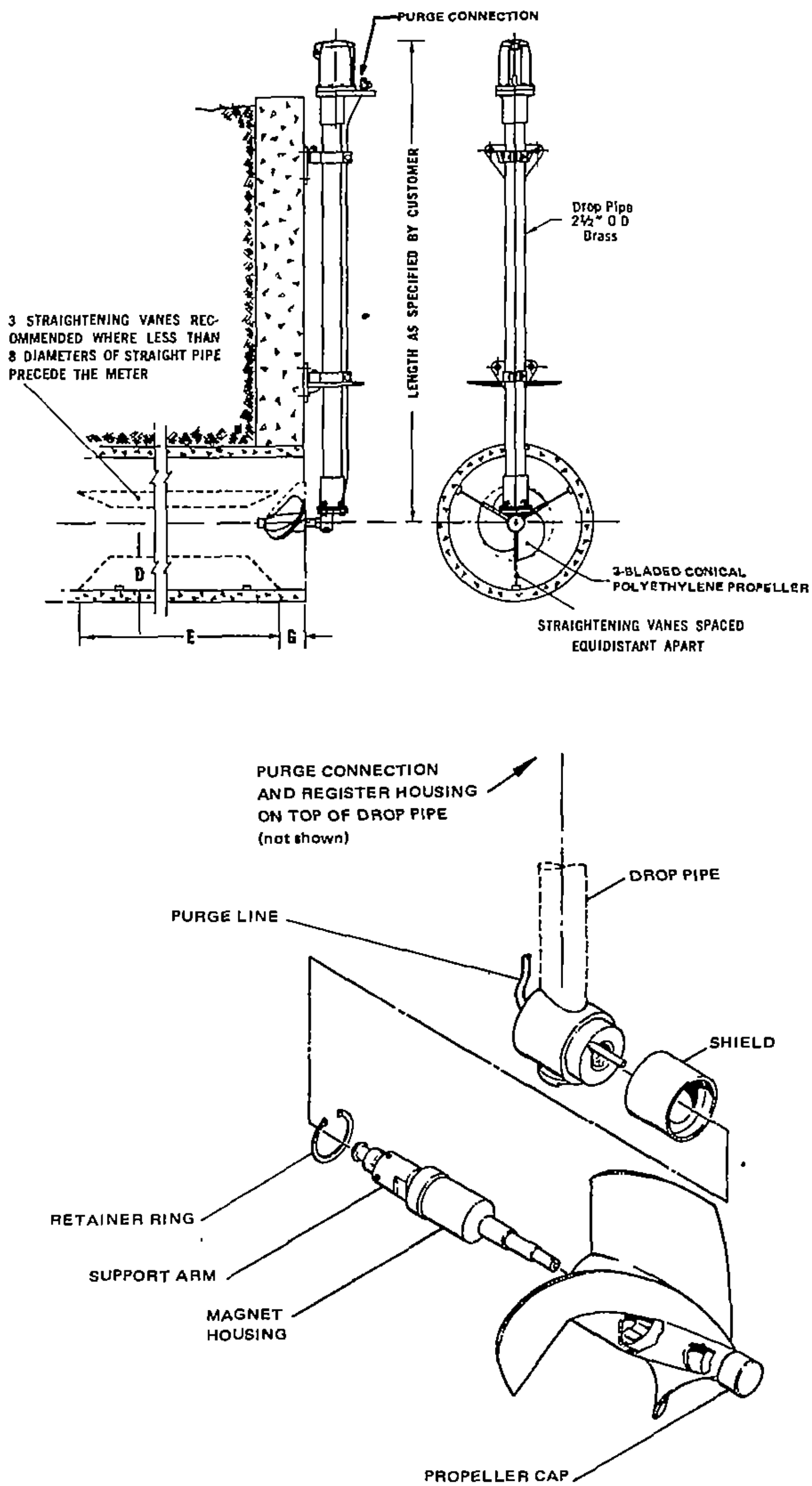

PURGE CONNECTION
LENGTH AS SPECIFIED BY CUSTOMER
Drop Pipe
2½" O D
Brass
3 STRAIGHTENING VANES REC-
OMMENDED WHERE LESS THAN
8 DIAMETERS OF STRAIGHT PIPE
PRECEDE THE METER
D
E
G
3-BLADED CONICAL
POLYETHYLENE PROPELLER
STRAIGHTENING VANES SPACED
EQUIDISTANT APART
PURGE CONNECTION
AND REGISTER HOUSING
ON TOP OF DROP PIPE
(not shown)
DROP PIPE
PURGE LINE
SHIELD
RETAINER RING
SUPPORT ARM
MAGNET
HOUSING
PROPELLER CAP

Figure A

COMMENTS:

Propeller meters are not recommended by Sparling for use in raw sewage and are unsuitable for a storm or combined sewer application.

MANUFACTURER: TAYLOR
SYBRON CORPORATION
TAYLOR INSTRUMENT PROCESS CONTROL DIVISION
TELEPHONE (716) 235-5000

PRODUCT LINE: ELECTROMAGNETIC FLOWMETERS, SUBMERSIBLE PROBES

DESCRIPTION:

Flowmeters - The "MAG-PIPE" 1100/1200 Series electromagnetic flowmeters measure flow by Faraday's Law of Magnetic Induction. A low-level, AC signal generated by the movement of a conductive fluid in a magnetic field is amplified by a solid-state transmitter which may be used directly with Taylor receiving instruments such as controllers, recorders, integrators, etc. Figure A shows a typical installation.

The 1100T or 1101T transmitters are used with Taylor 1100L, 1101L, 1200L, 1210L, 1211L, 1240L, and 1241L sensing heads. The 1100T is the remote unit and can be mounted up to 366 meters (1200 feet) from the sensing head. The 1101T is the integral form and is mounted directly on the sensing head; it produces a 4 to 20 mA DC signal which is linear with flow. The transmitters are completely solid state and incorporate thick film hybrid integrated circuits and an automatic quadrature rejection (or null adjustment) feature which eliminates costly and time-consuming start-up. If pneumatic output is required, the 1100L can be coupled to a Taylor 737 transmitter. Teflon is the standard liner material used in the "MAG-PIPE" 1100L sensing head, although a variety of other liner materials are offered.

The recently introduced Taylor 1210L series uses self-cleaning electrodes to eliminate the measurement problems caused by severe coating buildup. The electrode material used is Carpenter 20cb-3 stainless steel, which is ceramic coated for this application. Only a conductive "eye" (Figure B) for signal pickup is untreated; the eye protrudes into the higher velocity portion of the process stream which is said to have a cleansing action on the eye caused by the eye's unique geometric construction.

Submersible Probes - Taylor also manufactures a submersible probe for measuring flow in large process pipes of 50.8 cm (20 in.) I.D. or over. The probe is a 15.24 cm (6 in.) magnetic flowmeter consisting of platinum foil electrodes fired into a ceramic tube. The probe can be used with either a remote or integrally mounted transmitter. The assembly is welded to a mast which is fastened to a flange. When inserted into the process piping, the ±2% accuracies may be achieved when a symmetrical velocity profile exists at velocities above 0.6 m/s (2 fps). In addition, compensation can be made for non-symmetrical velocity profiles by field calibration techniques such as pitot traverses, dye dilution, or other acceptable methods.

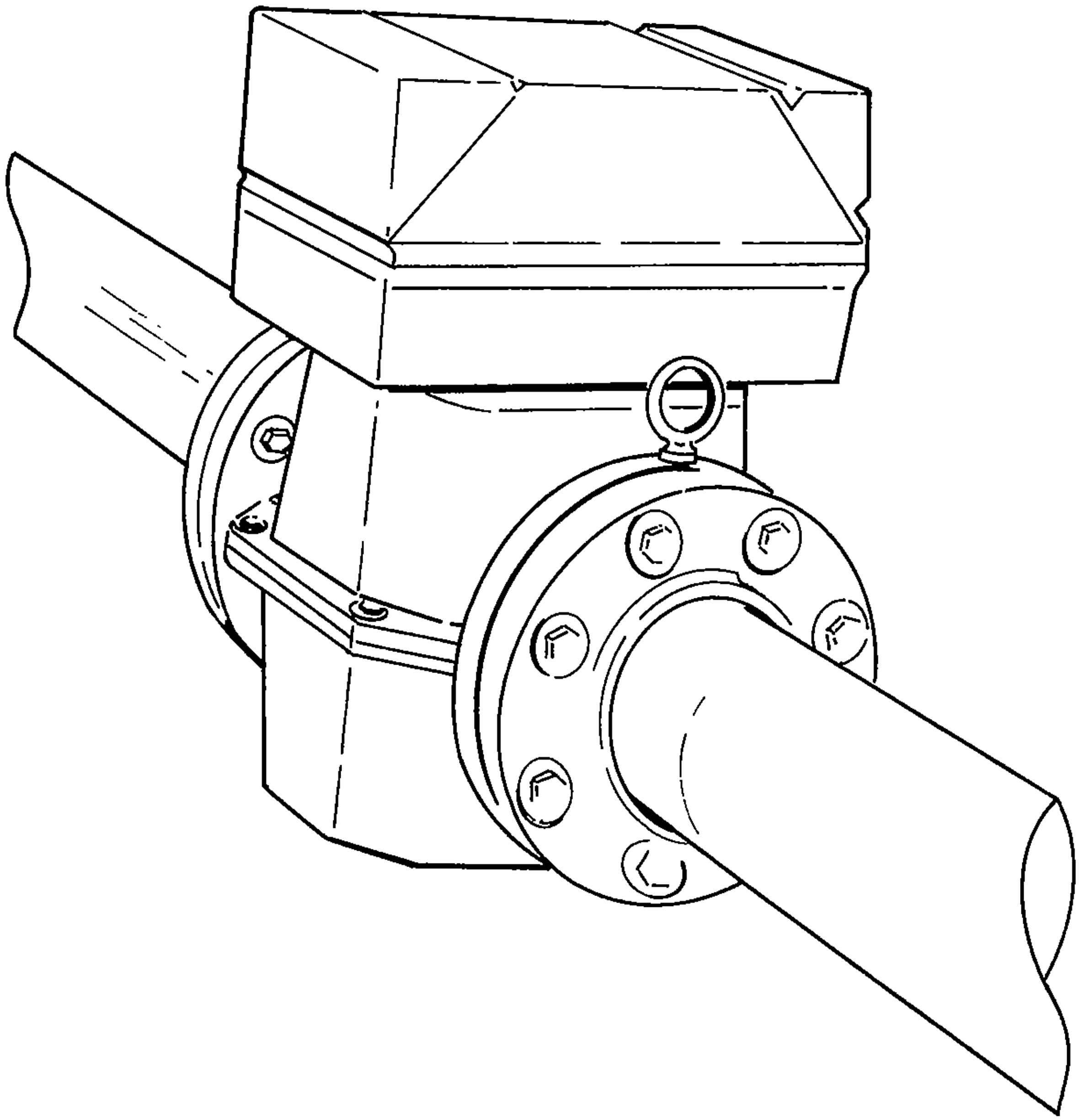
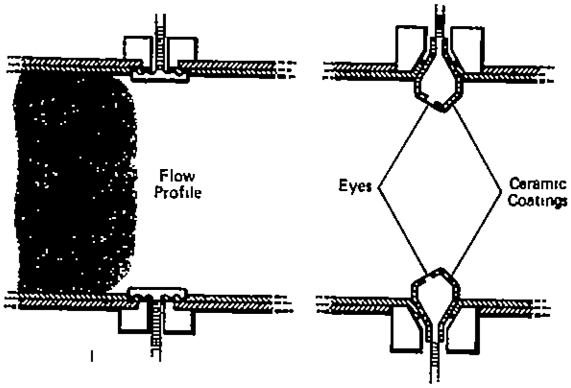


Figure A

Self-Cleaning Electrodes



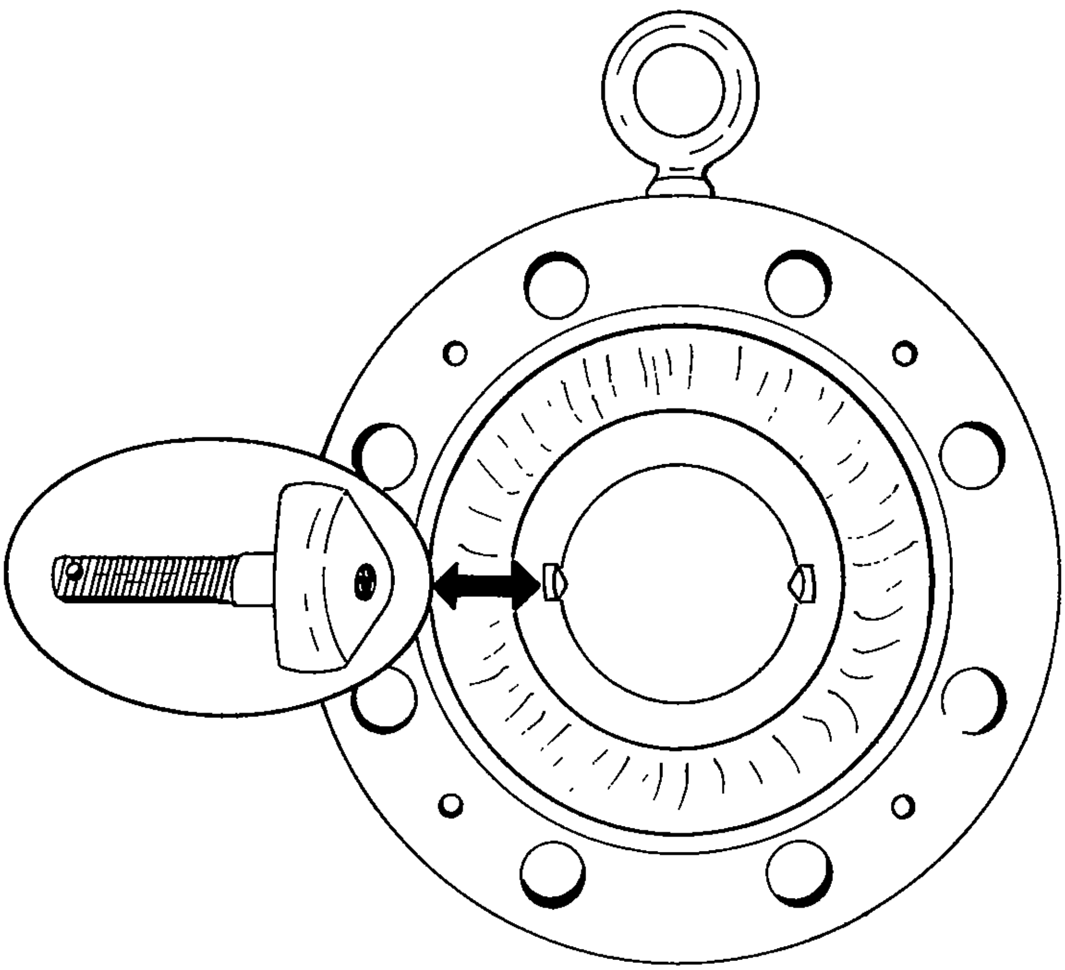


Figure B

SPECIFICATIONS:

1100/1200 Series Flowmeters (Typical)

Accuracy (including Sensing Head and Transmitter):	±1% of flow (Sensing Head and Transmitter calibrated separately)
	±0.5% of flow (Integral Mounting or Sensing Head and Transmitter calibrated together)
	±0.25% of flow between 0.91 and 4.57 m/s (3 and 15 FPS) (optimum calibration)
Repeatability (including Sensing Head and Transmitter:	±0.2% of flow
Flow Range:	0-0.9 to 0-9.0 m/s (0-3 to 0-30 fps)
Sensitivity (Approx)*:	300 microvolts rms/ft/sec
Output Signal**:	4-20 mA, DC
Minimum Process Conductivity:	Down to 1 micromho/cm
Power:	117 VAC, 50/60 Hz or 117 VAC/234 VAC, 50 Hz
Power Consumption**:	12 VA, 11.8 watts
Pipe Sizes:	2.54 cm (1 in.) to 30.48 cm (12 in.)
Weight:	6 kg (13 lb) - Transmitter; 20.4 kg (45 lb) to 109.0 kg (240 lg) - Sensing Head

PRICES: Sensing Heads, from $935.00 to approximately $5,000 (MAG-PIPE 1100 Series only)

Transmitters, Remote Mounted -- $810.00

Transmitters, Integrally Mounted on Sensing Head -- $791.00

COMMENTS:

The Taylor line of electromagnetic flowmeters features a number of what are claimed to be unique features that extend the utility of their devices. Electromagnetic flowmeters were discussed thoroughly in Section VI and will not be discussed further here.

---

* Sensing Head only

** Transmitter only

MANUFACTURER: THERMAL INSTRUMENT COMPANY
41 TERRY DRIVE
TREVOSE, PENNSYLVANIA 19047
TELEPHONE (215) 355-8400

PRODUCT LINE: THERMAL FLOWMETERS AND FLOW PROBES

DESCRIPTION:

The Thermal Instrument Company offers the Model 60 and 60-L thermal flowmeters which could be applicable to the measurement of combined sewage and stormwater; however, their Model 62-L thermal mass flow probe and thermal flow probe (no model number) do not appear to be suitable for this application because of the vulnerability of such probes to damage when inserted in effluent and stormwater flows having large quantities of suspended materials.

Model 60 Thermal Flowmeter - This device consists of a single, unobstructed flow tube having no moving parts. The meter utilizes the thermal boundary layer principle in which the sensing elements (i.e., temperature and flow) are located on the outer surface of the tube and never contact the flowing medium. The flow sensor is energized with a small amount of electrical energy (less than one watt); the heat conducted off this element, by the flow stream, is directly proportional to the mass flow rate of the fluid. Additional sensing elements are located on the tube to compensate and correct for the effects of fluid and ambient temperature. It is reported that any fluid can be metered, no matter how corrosive or abrasive. The meter is said to be not attitude sensitive and therefore can be mounted vertically to prevent the buildup of solid particles in slurries. The meter can be used with a variety of standard potentiometric recorder or control devices, standard industrial and military transducers, and digital readouts.

Model 60-L Thermal Flowmeter - The Model 60-L is a "spool piece" type meter and is similar to the Model 60 in basic operation, with one fundamental difference. The Model 60-L also has acquired level sensors on the outside diameter of the flow tube. Figure A is a diagram showing the location of the level and velocity elements in this combination meter body. The product of the readouts provided by the velocity and liquid level measuring sensors will give total instantaneous flow in a partially filled effluent duct, which usually is so designed that it will never operate completely full except under emergency conditions.

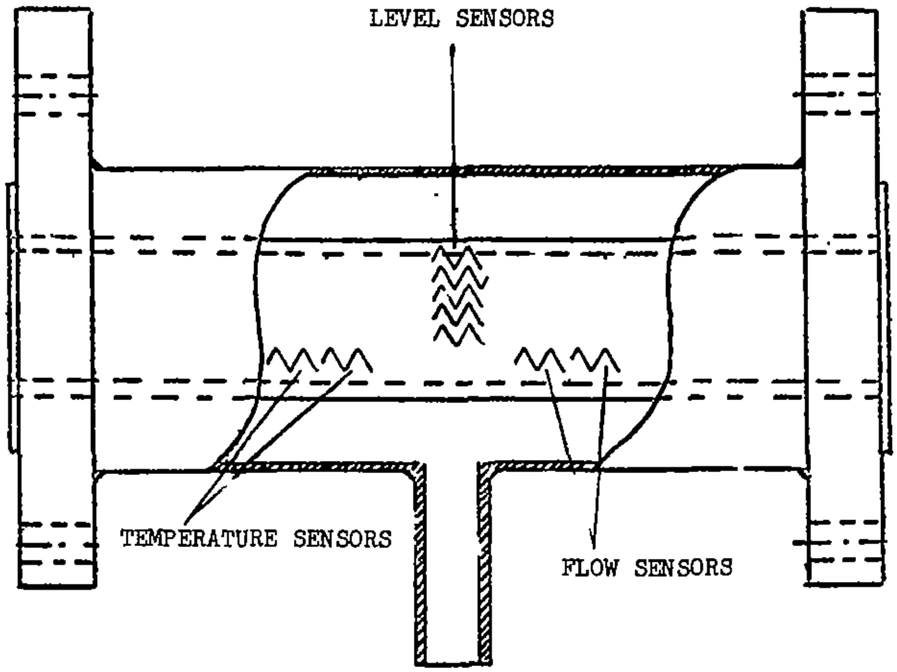


Figure A

SPECIFICATIONS:

Model 60 Thermal Flowmeter

Output:	0 to 10 mVDC signal to operate any standard potentiometric recorder or control device (standard)
	1 to 5, 4 to 20, 10 to 50 mA or 1 to 5 VDC for recording and control purposes (optional)
	3 to 15 psig or 3 to 30 psig pneumatic signals (optional)
	Digital readout with BCD (optional)
Flow Rate:	1 cc/min. (minimum); no upper limit
Accuracy:	±1%
Repeatability:	> ±0.2% of reading
Response Time:	1/2 sec.
Pipe Sizes:	up to 50.8 cm (20 in.)
Power:	115 VAC, 60 Hz, < 20 watts

Model 60-L Thermal Flowmeter

Accuracy: Velocity - 1%

Level - 1%

Overall - 2%

Other attributes are similar to Model 60.

PRICE:

Prices vary with size and particular specification details; a complete Model 60-L in a 61 cm (24 in.) size costs around $15,000.

COMMENTS:

The Thermal Instrument Company's products appear very suitable for measuring storm and combined sewer flows if all the manufacturer's claims are valid. No applications data on these fairly new devices are available for such services.

MANUFACTURER: TRI-AID SCIENCES, INC.
161 NORRIS DRIVE
ROCHESTER, NEW YORK 14610
TELEPHONE (716) 461-1660

PRODUCT LINE: ULTRASONIC FLOWMETER

DESCRIPTION:

The Tri-Aid Sciences temperature-compensating, ultrasonic flow measurement and transmitter system is designed for use with open channel flumes or weirs having a 3/2 power flow characteristics. The model FC-3-SW ultrasonic transmitter, when correctly installed and calibrated, will measure the water depth in front of the flume or weir.

This system consists of two basic components. The first is an enclosure housing the electronic control, integrated circuit flow characterizer, and transmitter. The second is an ultrasonic transducer "head" for bracket mounting above the water flow at the flume or weir. The transmitter and "head" are connected with a coaxial cable for the measuring signal and two wires for air temperature compensation. The system generates a high frequency sound pulse from the "head" mounted above the water flow. When the sonic pulse is reflected from the water's surface and received back, the control interprets the time delay period into water depth and the integrated circuit function module characterizes the signal into a linear 4 to 20 MADC flow signal output.

The transmitter is enclosed in a 40.6 X 35.6 X 15.2 cm (16X14X6 in.) oil- and dust-tight fiberglass enclosure for wall mounting. The explosion-proof "head" is encapsulated in Kynar to protect it from the effects of liquids and most industrial operating environments. The output signal from the FC-3-SW may be used to provide a remote input to a Tri-Aid integrator system for flow totalizing and sampling control. It may also be used with indicators, recorders, controllers, and/or computers to meet the customer's system requirements. The transmitter enclosure can be located up to 91m (300 ft) from the weir or flume. Typical installation details are shown in Figure A. Power requirements for the system are: 115 VAC, single phase, 10 amps, 60 Hz ±10%.

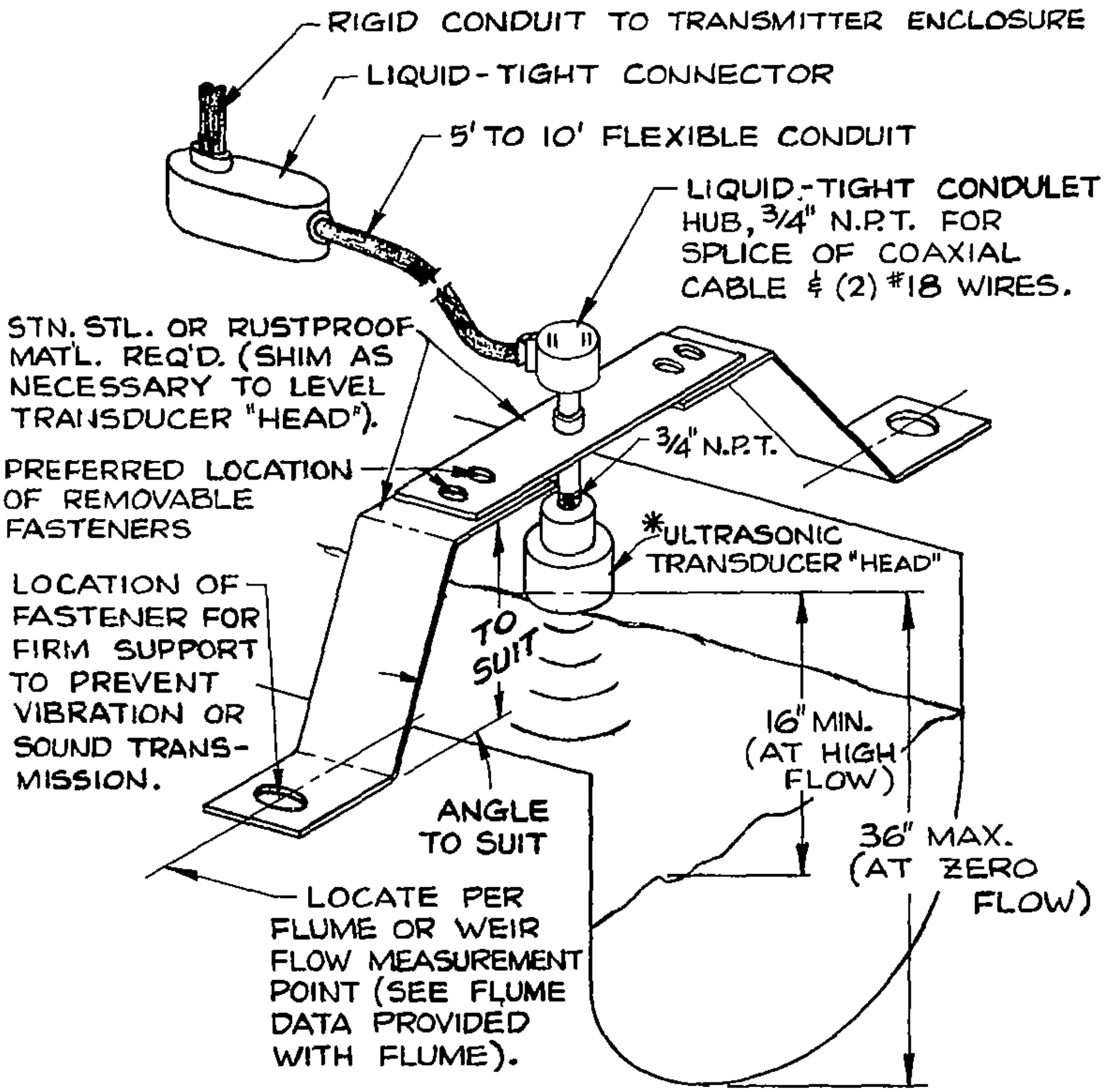
PRICE:

Not available at time of writing.

COMMENTS:

The 0.9m (3 ft) maximum distance from the face of the transducer head to the zero flow datum is for standard calibration. For special applications, this distance can be increased up to 6m (20 ft) to meet requirements for many storm or combined sewer applications.

TYPICAL ULTRASONIC TRANSDUCER (HEAD) MOUNTING



* NOTE:
BOTTOM SURFACE OF TRANSDUCER "HEAD" MUST BE PARALLEL TO LIQUID SURFACE.

Figure A

MANUFACTURER: UNIVERSAL ENGINEERED SYSTEMS, INC.
7071 COMMERCE CIRCLE
PLEASANTON, CALIFORNIA 94566
TELEPHONE (415) 462-1543

PRODUCT LINE: FLOWMETERING SYSTEMS (CONTROL CABINET, RECORDER, TOTALIZER, READOUTS)

DESCRIPTION:

UES offers its electronic FLO/Monitor flow measurement system in several different configurations - i.e., for permanent installations, remote or temporary locations, and intrinsically safe installations for "hazardous" area applications. Specifically designed for measuring wastewater flow in manholes, in effluent and influent lines, etc., this completely electronic system, which utilizes a Palmer-Bowlus flume for its primary element, does not employ floats, probes, mechanical linkages, or bubblers. The basic unit consists of a control cabinet and the measuring flume. The control cabinet contains the electronic circuits, flow recorder, flow totalizer, power supply, etc. The measuring flume carries an embedded sensor element which provides the electronic information relating water depth to flow. Figure A shows a typical temporary manhole installation.

Measuring Flume - The physical configuration and dimensions of this primary measuring device (Figure B) follow the standard Palmer-Bowlus concepts. Its smooth, acrylic-PVC plastic construction is rugged and causes little, if any, disturbance or restriction to water flow. Sizes to 30.5 cm (12 in.) are stock items; larger sizes may be obtained by special order.

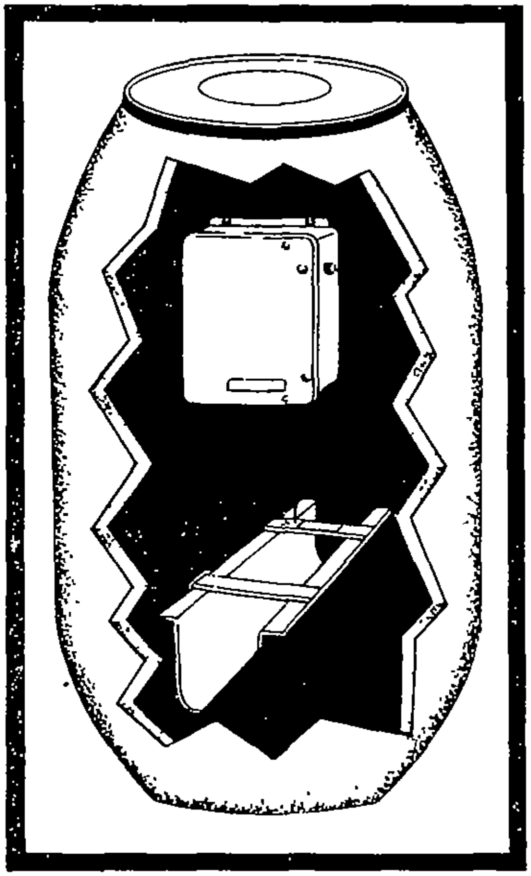
Flow Rate Recorder - This secondary device provides a 30-day, continuous strip chart for recording a permanent record of flow variations (rate vs time) in the sensing flume at all times. Special pressure-sensitive chart paper is used.

Flow Totalizer - This six-digit counter displays total flow volume through the flume in units from one thousand to one billion gallons.

Telemetering - Via a special operational plug provided with each monitor, flow rate and total flow information can be sent to central office terminals. Built-in logic circuits are provided for this purpose.

Remote Display - Up to 1525m (5000 ft) of 6-conductor, No. 20 gauge shielded wire can be provided as interconnecting cable between an optional remote display and the low-voltage FLO/Monitor computer (Model 8092 only). The remote display contains a flow rate recorder and a flow totalizer and an alarm to signal excessively high or low flow rate.

Temporary Location
Model 8091



Permanent Installation
Model 8090

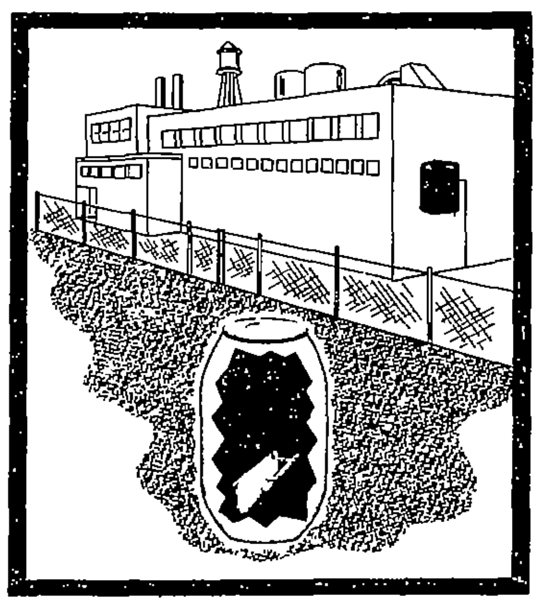


Figure A

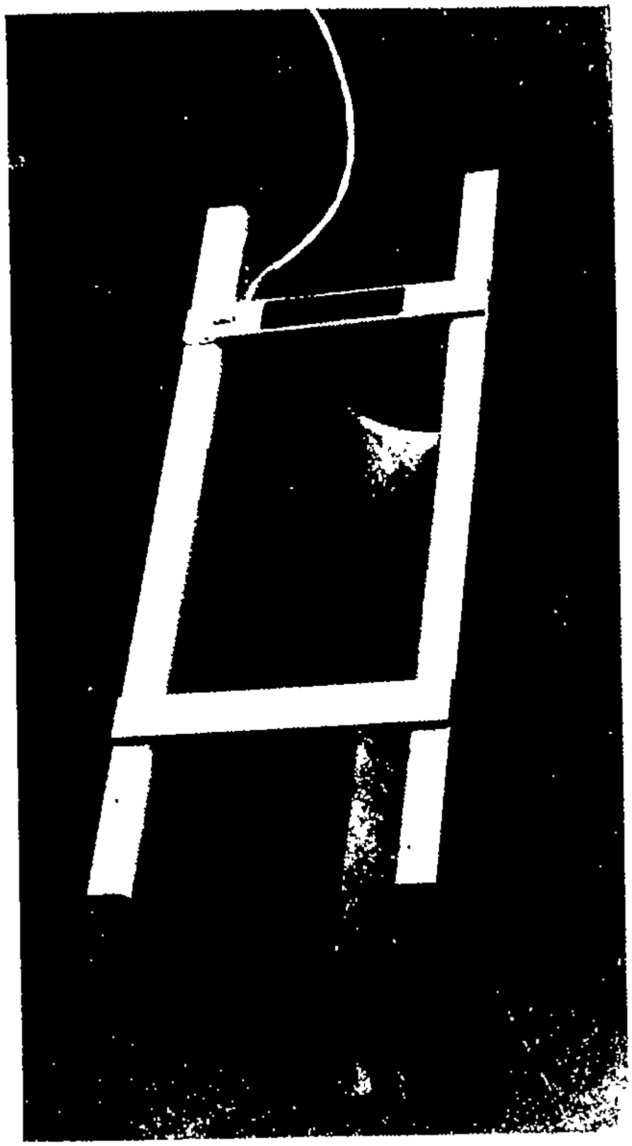


Figure B

SPECIFICATIONS:

Flume

Pipe Size - cm (in.)	Length - cm (in.)	Max Flow - MLPD (MGD)
10.2(4)	26.4(14)	.475(.125)
15.2(6)	50.8(20)	.95(.25)
20.3(8)	68.6(27)	1.90(.50)
25.4(10)	81.3(32)	3.42(.90)
30.5(12)	96.5(38)	5.32(1.40)

FLO/Monitor (All Models unless otherwise indicated)

Accuracy:	±4% full scale
Power:	120V 60 Hz 12V (Rechargeable gel-battery for 8091 FLO/Monitor)
Size:	
Control Cabinet	30.4x35.6x15.2 cm (12x14x6 in.)
Remote Display Unit (8092 only)	20.3x25.4x10.2 cm (8x10x4 in.)
FLO/Computer (8092 only)	20.3x25.4x10.2 cm (8x10x4 in.)
Weight:	
Control Cabinet (8090/8091)	9.07 kg (20 lb)
Power Supply (8091 only)	11.34 kg (25 lb)
Remote Display Unit (8092 only)	~4.54 kg (~10 lb)
FLO/Computer (8092 only)	~2.27 kg (~5 lb)
Temperature Range:	-1° to +49°C (30° to 120°F)
Price:	Not available at time of writing.

COMMENTS:

Using a characterized electronic probe embedded in the wall of the Palmer-Bowlus flume offers many advantages for storm or combined sewer application. However, the one-piece design will present size restrictions due to manhole entry dimensions.

MANUFACTURER: VICKERY-SIMMS, INC.
P.O. BOX 459
ARLINGTON, TEXAS 76010
TELEPHONE (817) 261-4446

PRODUCT LINE: ORIFICE PLATES, FLANGES, FITTINGS, AND METERING TUBES; ASME AND SHORT-FORM VENTURI TUBES; FLOW NOZZLES; PARSHALL FLUMES; TURBINE FLOWMETERS

DESCRIPTION:

Vickery-Simms is a long-established manufacturer of primary flow measurement devices. Each of their product lines will be discussed briefly.

Orifice Plates and Accessories - Vickery-Simms (VSI) maintains an environmentally-controlled atmosphere where concentric, eccentric, segmental, and quadrant edge orifice plates are bored to precision tolerances in conformance with AGA, ISA, and ASME recommendations (unless otherwise specified by the customer). Each plate is stamped with line size, ASA rating, material, and exact orifice bore. All plates which are beveled are stamped "inlet" on the square-edged side.

Sizes available for line diameters are from 1.3 to 229 cm (0.5 to 90 in.) in virtually any machinable material to suit the application. Types 302, 304, and 316 stainless steel, hastelloy, and monel are stocked for immediate delivery. Orifice flange unions, fittings to allow removal without interrupting service, straightening vanes, and meter runs for highest accuracy are also offered by VSI.

Flow Nozzles - VSI manufactures flow nozzles for critical and subcritical flow in accordance with ASME standards. These are available in carbon steel, chromo moly, and stainless steel in sizes from 2.5 to 76 cm (1 to 30 in.). For guaranteed accuracy, flow-calibrated meter runs are also manufactured.

Venturi Tubes - VSI manufactures a number of venturi tubes including a fabricated type (welded, not cast) ASME, a short form, and a low pressure loss venturi. The fabricated, long-form (ASME) venturi is lighter in weight and more durable than cast or forged venturis. The short-form venturi, while offering standard venturi accuracy (±0.75% uncalibrated), requires less laying length (four times the pipe diameter) and produces only slightly greater unrecovered pressure loss. The low pressure loss venturi or flow tube is a special design that maintains good uncalibrated accuracy (±1%) but offers only about one-fourth the pressure loss of a standard venturi (typically 3% with a beta ratio of 0.75).

All VSI venturi tubes are available in a wide range of standard sizes from 7.6 to 122 cm (3 to 48 in.) and four beta ratios (0.375, 0.490, 0.630, 0.750). Other sizes and ratios can be manufactured for special situations. A partial list of standard materials includes carbon steel, various stainless steels, cast iron, PVC, and fiberglass. Interior coatings of nickel plating, tungsten carbide, or glass lining are available to suit special applications. Insert types are offered as well as flanged and weld-in designs. Both single pressure tap designs as well as multiple taps with an interval annulus are offered.

Parshall Flumes - VSI manufactures Parshall flumes, in all sizes, made of fiberglass, steel, or prestressed concrete. They are available with or without a built-in electronic flow element (liquid height gage); rate indicators, recorders, and totalizers are also available.

Turbine Flowmeters - VSI manufactures insertion-type turbine flowmeters for use with or without a check valve. In-line types with threaded or flanged ends are also available. They are offered for use in pipe sizes from 7.6 to 244 cm (3 to 96 in.).

PRICES:

Prices were not available at time of writing.

COMMENTS:

VSI manufactures a wide line of primary flow measurement devices and will assist customers in assembling complete flow measurement systems. All of these devices were discussed in Section VI and will not be commented upon further here.

MANUFACTURER: WALLACE-MURRAY CORPORATION
CAROLINA FIBERGLASS PLANT
P.O. BOX 580
510 EAST JONES STREET
WILSON, NORTH CAROLINA 27893
TELEPHONE (919) 237-5371

PRODUCT LINE: PARSHALL FLUMES

DESCRIPTION:

Wallace-Murray manufactures a variety of products made of fiberglass reinforced plastics, including a line of standard Parshall flumes. These flumes feature maximum chemical and corrosion resistance, under normal conditions, through their use of polyester resins. Wallace-Murray offers flumes of varying depths and several optional features. Throat widths are available from 7.6 to 121.9 cm (3 to 48 in.); lengths range from 0.3 to approximately 3.35m (3 to 11 ft).

A standard feature of the Wallace-Murray flume is a head gage molded into the side of the flume at its lower end for the measurement of free flow discharges and flows under partially-submerged conditions. A free flow discharge graph is used in conjunction with the gage to determine flows under these conditions. Under submerged conditions, head flow must be measured at both upper and lower locations. By using flow correction curves, a determination of the flow loss due to submerged conditions can be made. Head gages at the second location are optioanl and will be supplied upon customer request.

Optional features of the Wallace-Murray devices include the incorporation, on some models, of a 30.5-cm (12-in.)-diameter floatwell (may be mounted on either side of the flume) or a 5-cm (2 in.) tap for the installation of a remote floatwell or bubbler system. A sanitary white gelcoat interior surface is also available. Installation design features of the flume includes the provision for free standing installation with additional reinforcing ribs or stiffeners optional for maximum stability instead of the standard loops for anchoring when used as liners in concrete.

PRICES:

Prices not available at time of writing.

COMMENTS:

Parshall flumes were discussed thoroughly in Section VI and will not be commented upon further here.

MANUFACTURER: WESMAR INDUSTRIAL SYSTEMS DIVISION
905 DEXTER AVENUE NORTH
SEATTLE, WASHINGTON 98109
TELEPHONE (206) 285-2420

PRODUCT LINE: ULTRASONIC MEASURING DEVICES

DESCRIPTION:

The Industrial Systems Division of WESMAR (Western Marine Electronics, Inc.) manufacturers several secondary liquid measurement devices utilizing the techniques of ultrasonic (sonar in air) ranging. These are the FM 9, a noncontact ultrasonic liquid level "flowmeter" for flumes and weirs, and SLM 9 and SLM 15 ultrasonic devices for the measurement of liquid levels. These devices are all readily adaptable to water and sewage applications.

FM 9 Flow Meter - Actually an echo-sounding instrument, the FM 9 represents a new concept of noncontact weir/flume flow measurement (actually level monitoring) involving no moving parts or mechanical linkage. An all solid-state device, the FM 9 (Figure A) consists basically of an electronics unit (control box), PVC-encapsulated sensor, a meter, and a junction box (JIC enclosure).

FOR:
RECTANGULAR WEIRS • CIPPOLETTI WEIRS • TRAPEZOIDAL WEIRS • "V NOTCH" WEIRS
PARABOLIC FLUMES • PARSHALL FLUMES • LEOPOLD-LAGCO FLUMES

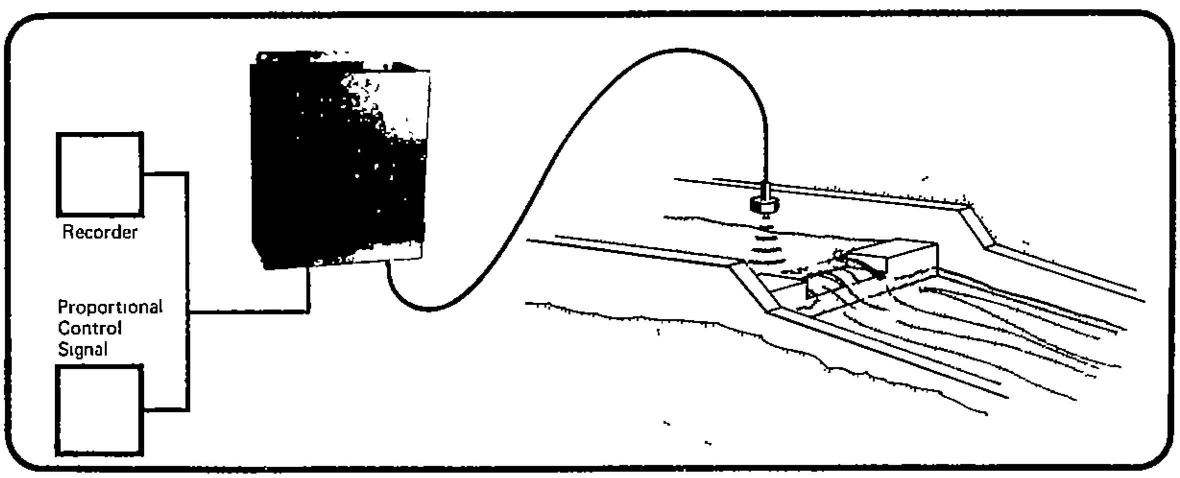


Figure A

This device employs a sensor, which is placed above the liquid level. A repetition rate generator in the electronics unit triggers an oscillator that sends a signal through a driver and power amplifier to the sensor which converts these pulses into high frequency sound waves. The sensor directs these acoustic signals downward to the material. The sensor detects the returning sound wave (echo) and converts it to an electrical signal. Precision timing circuits are used to measure the time delay for the echo to return. Processing of the electrical signals converts the pulse transmit time to an analog voltage or current proportional to the measurement distance. Output is available which represents height or flow. Temperature compensation circuitry neutralizes any temperature variations.

SLM 9/SLM 15 Level Monitor - These are short-range liquid level monitors which are entirely self-contained and are designed to interface with standard industrial meters, recorders, and equipment of all types. Solid state techniques, including the use of integrated circuits, have been employed.

A basic system consists of an electronics board (power supply, transmitter, receiver) and totally encapsulated PVC sensor. The SLM 9 provides noncontact level measurement for distances up to 3m (10 ft) from the sensor. Proportional 0-5 volt and 0-1 mA outputs are standard. Options include: 4 to 20 mA current output; various meters and enclosures; and five independently adjustable set points that may be set at desired level points for pump control, alarm indicators, or annunciators. Operating principles for liquid measurements are similar, from an electronic and acoustic standpoint, to those of the model FM 9 flow meter.

SPECIFICATIONS:

Range (minimum):	FM 9/SLM 9 - 41 cm (16 in.) SLM 15 - 46 cm (18 in.)
Range (maximum):	FM 9 - 3m (10 ft) SLM 9 - 3m (10 ft) (liquids) SLM 15 - 7m (20 ft) (liquids)
Resolution:	within 1%
Repeatability:	within 1%
Linearity:	within 1%
Output Signals:	FM 9/SLM 9 - 0 to 5 VDC 0 to 1 mADC SLM 15 - 0 to 5 VDC 0 to 1 mADC (1 to 5, 4 to 20, 10 -50 mADC)
Sensor Beam Pattern:	7° conical included angle

Input Power:	110/220 VAC, 50-60 Hz, 10 watts
Electronics to Sensor Remote Operation:	FM 9/SLM 9 - up to 91.4m (300 ft)* SLM 15 - up to 152.4m (500 ft)*
Dimensions (Enclosure)	30.4x25.4x12.7 cm (12x10x5 in.)
Weight:	
Electronics	0.91 kg (2 lb)
Sensors	0.45 kg (1 lb)

PRICES:

Only general cost guidelines can be provided due to the many variables. Complete systems range from $1,500 to $2,500. Sensors cost from $125 to $150 and control boards are from $500 to $800. Enclosures (junction boxes) are available from $25 to $500, depending upon size and NEMA rating.

COMMENTS:

Ultrasonic liquid height gages were discussed in Section VI and will not be commented on further here.

* Using Coaxial Cable RG620.

MANUFACTURER: WESTINGHOUSE ELECTRIC CORPORATION
OCEANIC DIVISION
P.O. BOX 1488, MAIL STOP 9R30
ANNAPOLIS, MARYLAND 21404
TELEPHONE (301) 765-5658

PRODUCT LINE: ACOUSTIC FLOWMETER

DESCRIPTION:

More than 10 years of research in the flow measurement field by Westinghouse has gone into the development of this acoustic measuring system. The Model L. E. (leading Edge) Flowmeter is so named because it uses only the leading edge of an acoustic pulse as a basis for determining liquid velocity and volume flow rate. While this flowmetering system was designed to measure water flows, the basic principle applies to most other liquids as well, including raw sewage.

Two ultrasonic transducers are installed in opposite walls of a conduit, with the line between them at an angle (45°, for example) with the conduit axis. The two transducers simultaneously transmit pulses of sound energy through the moving fluid. The pulse moving with the flow travels the distance between transducers in less time than the pulse moving against the flow. The system measures the transit time of the faster pulse and the difference between the transit times of the faster pulse and the slower pulse. Using these two time measurements, it solves two simultaneous equations in two unknowns - the sound velocity and the fluid velocity. Sound velocity can vary with changes in fluid temperature, salinity, and other properties. By measuring sound velocity and correcting for it, the system automatically maintains its accuracy for varying fluid conditions. Volumetric flow through a conduit is computed by integrating the local fluid velocity over the conduit cross section. The system does this by measuring local velocities along several paths, scaling these velocities for path geometry, and summing. A pair of transducers is required for each path. Four transducer pairs (four paths) will achieve better than 1% accuracy with any practical velocity profile. Volumetric flow in an open stream is computed in a like manner, except that water stage is measured and accounted for as it varies.

Figure A shows a basic acoustic configuration arrangement. Two probes are shown in the diagram, each with separate transducers and transmitters; however, in actual practice only one transducer is generally used in each probe, and both probes are energized by a common transmitter. The probes provide an unobstructed flow path without head loss.

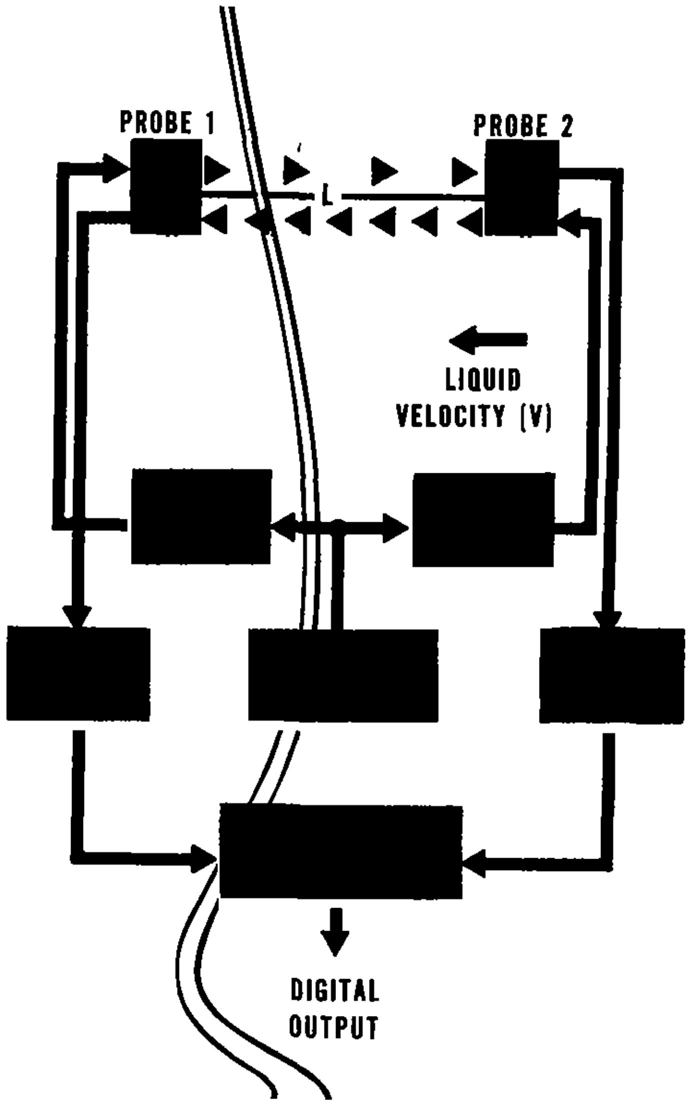


Figure A

The basic L.E. system consists of the transducers and transducer fittings, cabling, and a console housing the electronic circuitry and readouts. Four pairs of transducers are provided for flow in conduits; in open channel applications, the number of transducer pairs must be determined by the installation geometry.

SPECIFICATIONS:

Accuracies:	to 0.1% (demonstrated) in pipes from 0.3 to 9.14m (1 to 30 ft)
Operating Range:	10,000 to 1 (typical)
Power (Console):	115 VAC, 60 ±2 Hz, 3 amps, <500 watts
Flow Rate:	No upper limit. Flows approaching 16,990,000 ℓ/s (600,000 cfs) have been measured. Liquid velocities to >0.5 percent of full scale.
Dimensions (Console):	198x63.5x63.5 cm (78x25x25 in.)
Weight (Console):	136 kg (300 lb)

PRICE: $40,000 up

COMMENTS:

Section VI discusses the advantages and disadvantages of this type flowmeter. Cost, size, and complexity of this system mitigate against its use for many storm and combined sewer applications.

SECTION VIII

SELECTED PROJECT EXPERIENCE

In order to evaluate both standard, commercially available flow measurement equipment and custom engineered equipment in actual field use, a survey of recent USEPA projects in the storm and combined sewer pollution control area was conducted. Several USEPA projects designed solely to develop improved flow measurement equipment were included in the survey. Final reports were obtained where available, but for some projects only interim reports existed and, in a few instances, telephone conversations had to be relied on. The projects are discussed in general chronological order, starting with earlier efforts and finishing with current, on-going activities.

A survey of recent activities of several other Federal agencies in research and development of improved flow measuring devices and methods is also included herein. The responsibilities of these agencies include measurement of water, so they are familiar with flow measurement needs to fulfill their own objectives. In a few cases, these needs include measurement of stormwater and combined sewage. Contacts with key personnel of the agencies were made by personal interview, by telephone, and by letter.

CHARACTERIZATION AND TREATMENT OF COMBINED SEWER OVERFLOWS

Reference (73) describes a study whose general objectives were: (a) to develop workable systems to manage overflows from the combined sewers of San Francisco, thereby alleviating pollution and protecting beneficial uses of local receiving waters, and (b) to provide the rationale and methodology for controlling pollution from combined sewer overflows in other metropolitan areas of the United States.

Data collection for the project included measurement of dry weather flows of the Selby Street and Laguna Street trunk sewers and measurement of storm overflows from the two sewers. Eight storm overflows were monitored at the Selby Street outfall and two were monitored in the Laguna Street outfall. Monitoring included measurement of rainfall and discharge as well as the quality characteristics of the overflows.

The tracer dilution method was selected for use in measurement of dry weather flows. Pontacyl Brilliant Pink B fluorescent dye was used for the tracer, and quantitative analyses for the tracer were made with a Turner Model 110 Fluorometer. Selection of the tracer was based on the following advantages:

a. Only small quantities of dye are required because precise determination of the dye concentration is possible at 10^{-3} mg/ℓ. Thus cost and quantity requirements are reduced.

b. In most sewage flows the "background" of this particular dye is not significant. The amount of tracer does not have to be materially increased in order to eliminate spurious background effects.

c. The tracer is not significantly affected by the presence of materials normally found in sewage.

Use of the dilution method did not prove satisfactory for measurement of the Selby Street overflow. Uneven distribution of the tracer when injected resulted from exposed sludge banks, and there was insufficient turbulence for adequate mixing of the dye. Because of the resulting lack of reliable data, a Palmer-Bowlus flume with a 1.22m (4 ft) throat and 15 cm (6 in.) invert slab, constructed from 16 gauge galvanized sheet metal was installed. A continuous record of the upstream water level was obtained by mounting a Stevens water level recorder, operated by float, in a stilling well constructed of sandbags.

"Because of adequate mixing below the point of dye injection, the tracer dilution method gave consistent results at Laguna Street and no other method was used for flow determination."

Because of generally unsatisfactory conditions, several methods were used for the measurement of storm flow in the Selby Street outfall structure. These were:

a. Velocity determination with current meters at a point 15m (50 ft) above the outfall structure. Not considered to yield reliable data as the meters were immediately fouled with rags and other debris.

b. Differential head measurements over the broadcrested weirs of the outfall structure. Because of expected interference by tide gates, the theoretical head-discharge relationship for a broad-crested weir of similar shape was used for comparison purposes only.

c. Measurement of surface velocities in the outfall structure by timing the traverse of styrofoam floats across a measured control section. A factor of 0.64 was applied to surface velocities to convert to average velocity, thus accounting for both horizontal and vertical velocity distributions.

d. Measurement of vertical velocity profiles in the outfall structure with an especially designed current meter having low velocity sensitivity. This was to establish discharge values under low head conditions and to check the results of the surface velocity determinations.

Water levels in the outfall structure were continuously measured by means of a "bubbler" gage. A rating curve was developed from the results of the surface velocity determinations and the current meter measurements in the outfall structure. A theoretical curve computed from the broadcrested weir formula was approximately 10% larger than this developed curve.

Flow determinations in the Laguna Street overflow were made by measuring the depth of flow at the outfall sewer and calculating the discharge by means of the Manning equation. Use of the Manning equation was said to be justified because the slope of the outfall sewer is known, and a uniform reach extends about 210m (700 ft) upstream from the point at which depths of flow were determined.

STREAM POLLUTION AND ABATEMENT FROM COMBINED SEWER OVERFLOWS - BUCYRUS, OHIO

Reference (74) contains the results of a detailed engineering investigation and comprehensive technical study to evaluate the pollutional effects from combined sewer overflows on the Sandusky River at Bucyrus, Ohio, and to evaluate the benefits, economics and feasibility of alternate plans for pollution abatement from the combined sewer overflows. A year-long detailed sampling and laboratory analysis program was conducted on the combined sewer overflows in which the overflows were measured and sampled at three locations, comprising 64% of the city's sewered area, and the river flow was measured and sampled above and below Bucyrus.

Dry weather wastewater flow measurements were taken of the discharge from three sewer districts, the influent and effluent of the wastewater treatment plant, and the Sandusky River at upstream and downstream gages. A weir was installed in each of the three trunk sewers, a 90° V-notch weir, a 61 cm (24 in.) rectangular weir, and a 46 cm (18 in.) rectangular weir. For two days of the investigation, flows at the weirs were measured and sampled at 15-minute intervals for 24 hours. The Sandusky River, upstream and downstream, was measured and sampled at one-hour intervals for 24 hours. Also, the wastewater treatment plant influent and effluent were sampled at one-hour intervals and flow measurements taken from the plan records. No problems with equipment for measurement of dry weather flows were indicated.

To measure overflow during rainfall, rectangular weirs were built at each of three overflow points. The weirs were constructed of one-inch plywood, which was bolted onto (steel) angles imbedded in concrete. The weir plates were 2.4, 4.9, and 3.0 meters (8, 16, and 10 ft) long for Numbers 8, 17 and 23 overflows, respectively.

Water level recorders were mounted in instrument shelters 107 cm (42 in.) behind the weirs. The recorders were Stevens Type F Recorder, Model 68, with a 24 cm (9.6 in.) per day time scale and a 1:2 gage scale. All recorders were equipped with automatic starters which would start the clocks at predetermined water levels.

A continuous record of flow in the Sandusky River above and below Bucyrus was obtained for the study period. An existing recording gage operated by the U.S. Geological Survey located at the first bridge below the wastewater treatment plant was utilized for downstream flow measurements. A new gaging station was installed on the river 91m (300 ft) upstream from the first overflow point of the combined sewer system. A rating curve for the gage was plotted using standard gaging techniques. The recorders used at both gaging stations were the Stevens A35, with 1:6 gage scales. The time scales for the gages were 12.2 and 6 cm (4.8 and 2.4 in.) per day, for the upstream and downstream gages, respectively.

No specific problems with flow measurement equipment were reported. However, a tabulation of overflows indicates that no record was obtained at Numbers 8 and 23 overflows during some periods. Reasons for this loss of record were not given. No check on the accuracy of the records was made available.

ENGINEERING INVESTIGATION OF SEWER OVERFLOW PROBLEM - ROANOKE, VIRIGINA

Reference (75) reports on the results of investigations of 25% of Roanoke, Virginia's separate sanitary sewer system, on the amounts of infiltration for various storm intensities and durations, and on the amounts of sewage overflow from the system.

Flows in three sanitary sewer interceptors, and streams draining the corresponding basins, were gaged during storm events to measure infiltration and runoff quantities and to establish their relation to rainfall intensities and durations. After significant variation in dry weather flows was observed, continuous monitoring of flows in the interceptors was maintained. Overflows bypassing the Water Pollution Control Plant were measured during rainfall events.

Sharp-crested weirs were used to measure flows in two of the streams. In the third stream, a stage-discharge curve was developed from the Manning formula using the measured hydraulic characteristics of the stream. In two of the interceptor sewers, and in the Water Pollution Control Plant overflow, a stage-discharge curve based on the Manning formula and the measured hydraulic characteristics of the sewer were used to convert depth measurements to flow estimates. In the third interceptor sewer, dry weather flows were estimated using the Manning formula, but during rainfall events the sewer became surcharged and overflow was measured by means of a weir installed in the side of the manhole wall.

No problems with use of the streamflow measurement devices and methods were noted. However, accuracy of measurements with use of the Manning formula in the natural stream channel photographed must be considered very poor. A photograph of one of the weirs used for streamflow measurement shows a significant accumulation of trash and debris on the weir. Under this condition, accuracy must be considered poor. Hydrographs indicated that two of the interceptor sewers were surcharged during many of the storms, and a record of discharge was not obtained during those periods.

Water levels at the gaging sites were recorded by means of six float-actuated, continuous water-level recorders manufactured by the Instruments Corporation (now a part of Belfort Instrument Company), and one pressure type recorder manufactured by the Bristol Company. After the float-actuated recorders were serviced and supplied with an expanded time scale, they performed satisfactorily for the duration of the program. During dry-weather periods, the bubbler pipe in the Bristol recorder collected debris and required frequent cleaning. Because of this maintenance problem, it was replaced with a float-actuated, continuous water-stage recorder.

COMBINED SEWER OVERFLOW ABATEMENT ALTERNATIVES - WASHINGTON, D.C.

Reference (76) reports on a project whose objectives were to: (a) define the characteristics of urban runoff in the subject area; (b) investigate the feasibility of high-rate filtration for treatment of combined sewer overflow; and (c) develop and evaluate alternative methods of solution.

Investigative activities included field monitoring of combined sewer overflows at two sites, and of separated stormwater discharges at one site. The monitoring program was conducted over a period of about six months, April 1 to September 23, 1969.

Selection of a satisfactory technique for flow measurement presented a problem. Weirs were not used because backwater elevations would have caused surcharging and flooding at the expected high flow rates. Depth of flow measurements with the use of a steady state empirical equation such as the Manning equation for calculating flow was not used because flow conditions were not steady state during periods of storm runoff. The method selected was use of lithium chloride as a tracer in a procedure similar to that of the salt dilution method (continuous injection type). Use of a lithium salt is said to improve the technique because the background of lithium in wastewater is usually low, and because lithium concentrations at fractional parts per million levels can be accurately and conveniently determined by atomic absorption or flame emission spectroscopy. The slope-area method was used as a check.

A number of difficulties experienced in use of the equipment resulted in loss of flow record during several major storms. Greatest trouble was in clogging or damage to the submersible pump used to collect samples of wastewater required for measuring lithium chloride concentration. Flooding of one of the lithium chloride release stations caused damage to the bubbler instruments used to measure water stage, to the lithium chloride release system, and to other equipment.

Flow rate estimates based on depth-of-flow measurements and the Manning formula were compared with results of the tracer method. Only a very general correlation with significant spread resulted. Large differences in flow were attributed to inaccurate measurement of depth of flow and the assumption of steady-state conditions inherent in Manning's formula.

URBAN RUNOFF CHARACTERISTICS

Reference (77) is an interim report on investigations for the refinement of the comprehensive EPA Storm Water Management Model.

"Detailed information on the watershed characteristics and data on runoff quantity and quality have been compiled from a one year study of a combined sewer watershed of approximately 2380 acres in Cincinnati, Ohio. Collection of these data is planned to continue over a three year period."

Flows at three sites in the sewer watershed were monitored. At two of the sites, flow was actually measured in two tributary sewers immediately upstream from their junction. The third site was at the outlet of the watershed; thus, five sets of flow measuring equipment were used.

"The flow measuring apparatus consists of a compressor, a manometer, and a Taylor pressure-type recorder. This recorder operates by measuring the pressure due to the depth and velocity of water flowing into the pipe by bubbling air through a long tube inserted into the water. The gage releases air at a constant pressure and as the depth and the velocity of flow changes, the pressure differential is recorded on a circular chart in inches of water. This pressure differential is actually the specific energy which is equal to the sum of the pressure head (depth of flow y) and the velocity head ($V^2/2g$). To obtain readily the discharge corresponding to the measured specific energy, Manning's equation has been used to express the depth and the velocity of flow as functions of the discharge and the hydraulic radius of the sewer cross sections."

Thus, curves have been calculated relating the measured specific energy and the corresponding discharge at the five measured locations.

Apparently, the value of slope used in the Manning formula was that of the sewer line at each of the five measuring sites. A photograph in the report shows a heavy, metal, top-hanging gate at the outlet of the sewer watershed. The outlet flow monitoring site is described as about 6m (20 ft) upstream from this gate. If this is the case, flow past the site probably would not be uniform, and the Manning formula would not be applicable.

Flows in the two pairs of sewers just upstream from their junction with the two sewers to be monitored would be controlled by the slopes of each of the two monitored sewers rather than the slopes of the four tributary sewers immediately upstream, which were the slopes in the Manning formula to compute flow. In any case, water surface slope is more properly used with the Manning formula than is the sewer slope.

Plotting of storm hydrographs for the measured sites discloses a number of serious inconsistencies in the data.

STORM AND COMBINED SEWER POLLUTION SOURCES AND ABATEMENT - ATLANTA, GEORGIA

Reference (78) reports on a study of six urban drainage basins within the City of Atlanta, Georgia, served by combined and separate sewers, to determine the major pollution sources during storm events. Rainfall frequency analysis and simulation techniques were utilized to obtain design criteria for alternative pollution abatement schemes.

Measurements of flow were made of three major overflows, as well as of the interceptor sewers originating at these points of overflow. Three branches of South River were measured, as was the South River main stream at four points. A bypass at the interceptor entering one of the wastewater treatment plants was measured.

Data were collected from January 1969 until April 1970. Continuous flow monitoring was maintained at the river and its tributary stations, and in the interceptors where dry weather flow characteristics were of interest. Event monitoring only was conducted of overflows and of the bypass to the treatment plant.

Rating curves for all gaging stations were developed by stage-discharge measurements with current meters. Either Price Type AA or Pigmy Type current meters were used. Some discharge measurements were verified by alternate methods or formulas, but results of these verifications are not given.

Stevens Type F water level recorders were used throughout. Gaging stations were reported to be constructed in accordance with established U.S. Geological Survey practice. For flow level recording at interceptors, scow floats were installed at manholes a short distance downstream from regulators.

Although probable accuracy of the records collected was not reported, an indication of their accuracy is available, based on one of the gaging stations in the project which was operated by the U.S. Geological Survey. This station, having a drainage area of 3.86 sq km (1.49 sq mi), had been operated since October 1963, or for more than six years. The greatest flow measured by current meter during the period was 5947 l/s (210 cfs), but the rating curve was extended to 23,220 l/s (820 cfs) by computation of flow through a culvert. Records at the station are stated by the USGS as poor, with no qualification.

STORMWATER PROBLEMS AND CONTROL IN SANITARY SEWERS - OAKLAND AND BERKELEY, CALIF.

Reference (79) describes an engineering investigation conducted on stormwater infiltration into sanitary sewers and associated problems in the East Bay Municipal Utility District, Special District No. 1, with assistance from the cities of Oakland and Berkeley, California. Rainfall and sewer flow data were obtained in selected study sub-areas that characterized the land used patterns predominant in the study area. Results obtained were extrapolated over large areas.

Palmer-Bowlus flumes were installed at three of the ten metering stations established specifically for the study. These flumes were constructed of stainless steel and were designed to fit the respective sizes and shapes of the sewers. They were mounted in the outlet sewer from the manholes so that head measurements could be made at the proper distances upstream from the throats. Wooden channel extensions through the manholes were installed to prevent water spreading out in the manhole as depth in the sewer increased.

At seven of the new metering stations, 90-degree, V-notch weirs were installed. These were constructed of marine plywood and covered for additional water resistance with two coats of polyurethane finish. For ease of installation, a channel closure was provided so that it could be easily slipped down into the flowing sewage and quickly bolted in position after installing and sealing the actual weir plate. Stevens type 2A35 water stage recorders were used at three weir locations where submergence of the weir was anticipated. These recorders were selected for the ability to record two liquid levels simultaneously, upstream and downstream from the weir.

Taylor pressure recorders were installed at the other seven new metering stations. With these recorders, liquid level sensing consists of measuring the back pressure from a continuously purging nitrogen gas bubble system.

In several cases, equipment was installed in manholes near the centers of streets, thus complicating the installation and use of equipment. Otherwise, no problems were noted with the use of the equipment at the newly established stations.

The flow rate at two pumping stations was determined by means of a system-head curve for the station which gives the discharge rate for each pump or combination of pumps. A recording ammeter was attached to the pump electrical leads to indicate the total number of pumps running at any given time. Relief overflow at one of these pumping stations was measured by means of a broad-crested weir and a wet-well liquid level recorder.

A third pumping station was equipped with both a wet-well liquid level recorder and a flow recorder. The primary device for the flow recorder was a venturi flow tube mounted on the discharge manifold of the pumps.

The influent pumping station at the water pollution control plant was equipped with individual flowmeters on each pump discharge which were connected to a combined flow recorder. The primary devices for the flow recorder were the discharge weirs in the grit chambers which reflect the respective pump discharge rates.

A pumping station relief overflow structure was provided with a flow measuring device for measuring the volume of water that overflowed. The flow measuring arrangement consisted of measuring the liquid levels on both sides of a rectangular tide gate and extracting the flows from the manufacturers rating curve. Because of difficulties in installation and operation, no usable flow measurements were obtained during periods of overflow.

DISPATCHING SYSTEM FOR CONTROL OF COMBINED SEWER LOSSES

Reference (80) describes a regulator control system which is said to demonstrate impressive reductions in combined sewer overflow pollution of the Mississippi River in Minneapolis and Saint Paul.

A mathematical model has been prepared that will, using rain gage data for inputs, (a) perform rainfall runoff analysis; (b) divert combined sewer runoff hydrographs at the regulators; and (c) route the diverted hydrographs through the interceptor system. This model will assist in operation of the system to retain combined sewer flows and utilize the maximum flow capacity of the existing interceptor sewer system.

The project includes a computer-based data acquisition and control system that permits remote control of modified combined sewer regulators. Data from rain gages, regulator control devices, trunk sewers and interceptors, and river quality monitors provide real-time operating information.

Water surface elevations in the system were monitored at about 48 points by the installation of bubbler gages employing a pressure-carrying tube installed in the sewer, an air-supply cylinder, a bubbler, a pressure transducer, and a telemetry unit for transmitting data to a central location. This equipment provided information on the frequency and duration of overflows. Because flow rate was not measured, data on the volume of overflows were not thus determined.

Flow in each of the three Minneapolis interceptors at the Minneapolis-St. Paul city line, was metered by dual venturi meters in each interceptor. This equipment, which was in use prior to the subject study, provides information on the effectiveness of the program to use the interceptors for temporary storage of combined sewage. Flow data in the interceptors served to provide a check on the accuracy of rainfall runoff modeling. Probable error of flow measurement by the venturi-meters was not discussed.

PRECONSTRUCTION EVALUATION OF COMBINED SEWAGE DETENTION FACILITIES

Reference (81) presents the result of a lengthy study of combined sewer flows in Somersworth, New Hampshire prior to construction of detention facilities. "*In order to get reasonably accurate and reliable flow measurements it was necessary to replace a section of the outfall with a weir pit large enough to provide a fair amount of stilling behind the weir.*" This weir pit was 1.8 x 1.8 x 7.5m (6x6x24.75 ft), and the weir was located 5.6m (18.33 ft) from the inlet.

Three different 0.63 cm (1/4 in.) thick steel plate rectangular weirs with crest lengths of 0.3, 1.2, and 1.7m (1, 4, and 5.6 ft) were used, the 1.2m (4 ft) one being employed for all but three months of the year-long study. The design was such that the different weirs could be changed easily in several minutes. The main difference in the 1.2m (4 ft) weir was that its crest was elevated 1.2m (4 ft) above the floor of the weir pit as opposed to 0.76m (2.5 ft) for the other two. This weir was constructed after initial operation with the 0.3 and 1.7m (1 and 5.6 ft) weirs, and "observation of high flow rates using the 5.6' weir indicated that it was desirable to increase the stilling in the weir pit by raising the crest height."

"*Head measurements over the 12" and 5.6' weirs were made using an air operated Fischer and Porter recorder. A float operated transmitter and recorder manufactured by the Penn/Measure-Rite Division of Badger Meter Manufacturing Company was used for head measurements over the 4' weir. Both recorders were set up to use 24 hour, 12" diameter charts. The Fischer and Porter recorder charts had a range of 0 to 20 inches of head, and the Penn/Measure-Rite Recorder charts had a range of 0 to 30 inches.*

"Flow into the weir pit was such that some turbulence was created in the weir pit. This caused the flow recorders to print out head measurements in short vertical strokes instead of a smooth line. This condition was corrected as much as possible by the addition of the 4' weir which had a crest 18" higher than the 12" and 5.6' weirs. The added depth of water in the weir pit tended to keep the turbulence at a minimum.

Sludge build-up behind the weirs did not appear to upset the hydraulic characteristics of the weirs. However, before any sampling programs were undertaken, the sludge build-up was totally removed from behind the weirs in order to obtain accurate chemical and biological characteristics of the combined sewage flow. The actual sludge build-up would occur within a couple of days after the installation of a weir. The majority of sludge in this combined sewage flow consisted of grit with a small percentage of organic matter."

Head measurements were "... converted to flows using appropriate formulae for the rectangular weirs used in the weir pit." By this it is assumed that the Kindsvater-Carter equation was used rather than the Francis formula, which would require corrections for both less than standard contraction and velocity of approach much of the time. For example, at the maximum head of 0.6m (2 ft) on the 1.2m (4 ft) weir (any greater head would overflow the 1.8m deep weir pit) the Kindsvater-Carter equation indicates a discharge of around 91 MLD (24 MGD), whereas the uncorrected Francis formula yields approximately 83 MLD (22 MGD), a 10% difference. The maximum discharge for the 1.7m (5.6 ft), as computed assuming the recorder's full 51 cm (20 in.) of head was used, is approximately 98 MLD (26 MGD). Maximum flow rates recorded with the 1.2m (4 ft) weir of from 99 to 148 MLD (26.2 to 39.0 MGD) are reported but not explained. It is possible that the 148 MLD (39.0 MGD) discharge was estimated but not so indicated. The point is that high accuracies should not necessarily be expected with the given installation at the higher flow rates.

URBAN STORM RUNOFF AND COMBINED SEWER OVERFLOW POLLUTION - SACRAMENTO, CALIFORNIA

Reference (82) contains the results of a program to develop a general method for determining the extent of pollution resulting from stormwater runoff and combined sewer overflows occurring in an urban area, and the application of this method to the City of Sacramento, California.

Combined sewage and stormwater in the system were characterized by collecting samples and measuring flows at each of 19 sampling locations during six wet weather periods. The intention was to collect, as nearly as practical, at the commencement of rainfall, three hours thereafter, and approximately 12 to 18 hours after the commencement of sampling.

However, comparison with rainfall records indicates that the first data of each storm period were not collected until the time of maximum rainfall intensity, or later.

The wastewater flows were established at manhole sampling stations by use of the Manning formula. The coefficient of roughness was assumed to be 0.013, a design value used by the City of Sacramento Engineering Department. The value of S used was the measured slope of either the water surface or the invert. Because of difficulties in making the required measurements for determination of slope, flow data at three of the stormwater runoff sites are not considered to be reliable. None of the computed wastewater flows at manhole sampling stations were checked by means of flow measurement equipment.

For design purposes, the peak stormwater runoff flow in each of the individual pipes comprising the Sacramento collection and conveyance system was estimated from rainfall records by use of the rational method. These estimated flows for a full pipe condition can be checked at three locations with computed flows at the manhole sampling stations. They differ with the computed flows by -6, +4, and -32 percent. This agreement is exceptional, particularly as these are the three locations where the computed flows are not considered to be reliable.

STORAGE AND TREATMENT OF COMBINED SEWER OVERFLOWS

Reference (83) describes a project to demonstrate the feasibility and economic effectiveness of a combined wastewater overflow detention basin.

"A paved asphalt detention basin with a storage volume of 8.66 acre-feet was constructed at Chippewa Falls, Wisconsin to receive overflow from a 90-acre combined sewer area including all of the central business district. The system was designed so that the stored combined sewage could be pumped to the wastewater treatment plant when precipitation subsided.

During 1969, due to dry weather, the pond received only sixteen discharges, but completely filled twice and overflow to the river occurred. During 1970, there were 46 discharges and the pond filled once, overflowing to the river. Over the two year period, 37.75 million gallons of combined sewage (93.7 percent of the total discharge volume) were withheld from the river for subsequent treatment."

Overflow from the combined sewer area to the detention basin was measured by a Palmer-Bowlus flume installed in a 198 cm (78 in.) reinforced concrete pipe. The flume was designed as outlined by Ludwig and Ludwig (33). It was fabricated of steel, and installed in the concrete pipe as it was laid. Space between the flume and pipe was grouted.

A Stevens Type A35 water-level recorder with a scow float was installed in the pipe to measure head on the flume. The chart time scale was 73.2 cm (28.8 in.) per day and the gage scale was 1:6. The volume discharged into the pond was computed from the recorded head on the flume and a rating curve for the flume, which was approximated in four linear sections. Discharges indicated by rainfalls on eleven different occasions were missed due to the recorder being out of order. Thus, eleven percent of the runoff events were missed.

Overflow from the pond to the river was measured by a 6.7m (22 ft) long sharp crested weir located in the overflow structure. The weir head was measured by a Stevens Type A35 water-level recorder with a cylindrical float. The chart time scale was 24.4 cm (9.6 in.) per day and the gage scale was 1:6. The recorder was out of order during one of the three overflow events which occurred during the period of project operation.

Flows to the wastewater treatment plant were measured by a meter in the plant which was not described. Apparently, this record is complete.

A THERMAL WAVE FLOWMETER FOR MEASURING COMBINED SEWER FLOWS

Reference (64) is a final report for a project to study the application of thermal techniques to the measurement of flow rates in combined sewers. The volume flow rate was to be computed as the product of average flow velocity in the sewer, and cross-sectional area of flow as determined from a stage measurement.

The use of flush-mounted hot wire or hot film anemometers in a direct reading mode for measurement of average flow velocity was extensively investigated. It was concluded that application of hot film anemometry techniques to commercial application of measuring sewer effluent for extended periods of time was not feasible. Major reasons for this conclusion are: (a) changes in calibration occur due to contamination film build-up; (b) breakdown of protective coatings over long periods of time; (c) change in calibration that occurs due to dissolved gases coming out of solution and depositing on the film element as bubbles; and (d) the physical vulnerability of available probe configurations combined with the difficulty of continuously measuring average velocity.

The thermal wave flow measurement system as developed incorporates five thermal sensors mounted on the inside periphery of the pipe. Measurement of the average flow velocity in the pipe is obtained by averaging the longitudinal propagation velocities of the five thermal waves generated at the five symmetric peripheral positions. Tests of a prototype unit indicated that this configuration does not provide signals which have adequate precision to measure fluid flow with the desired accuracy. The dissipation of heat was determined to be quite large, as was the ratio of the average stream velocity to the apparent boundary layer velocity.

The stage measuring system utilizes an electronic liquid level gage which consists of two solid rods formed to fit the inside curvature of the sewer pipe. One rod is driven by an electrical signal, and the other rod acts as a variable tap whose output varies as a function of water level. The instrument is capable of accuracies better than 1 percent of full scale. This is a commercially available system manufactured by Marsh and McBirney, Inc.

WASTEWATER FLOW MEASUREMENT IN SEWERS USING ULTRASOUND

Reference (84) describes the use of newly developed ultrasonic velocity measurement equipment in conjunction with ultrasonic level measurement equipment for the measurement of sewage flow.

"Each of two existing (combined) sewers in the Milwaukee (Wisconsin) Sewerage System, one 12-1/2 ft and the other 5 ft in diameter, were thus equipped initially. Subsequent discovery of an excessive amount of entrained air at the 12-1/2 ft diameter sewer site necessitated the transferral of that equipment to a more favorable location upstream in a 12-foot diameter sewer. Performance of the ultrasonic meters was compared with other metering devices at each of the locations. Relationships between average volume flow, water level, and average velocity along selected horizontal chords of the sewer cross sections were determined. A continuous record of flow was displayed and recorded. The unit installed in the 5-foot diameter sewer has operated for a period of 18 months without failure and has required only routine maintenance. Similarly the relocated unit installed at the 12-foot diameter sewer site has operated without failure since its installation. No deterioration of the ultrasonic transducer probes has been detected to date indicating their suitability for use in the sewer environment. The electronics of the ultrasonic velocity metering unit were modified to include peak protection, automatic gain control, and automatic trigger control to minimize the effects of variations in the solids loading."

Further observations concerning use of the ultrasonic equipment are as follows:

a. Similar equipment has been used in Japan to successfully measure full pipe flow of return sludge with high solids loadings. For practical line diameters, say from 0.2 to 5m (0.5 to 16 ft), no operational limitations due to suspended solids would be expected.

b. Entrained air bubbles were found to cause operational problems because of dissipation of the ultrasonic pulse due to scattering by the bubbles. Therefore, it is recommended that measurement sites be selected which are reasonably free of severe upstream agitation which would cause air entrainment.

c. Difficulties with level gage performance resulted from standing ripples in the sewage surface which interfered with echo returns. This was alleviated by moving the level sensor a few feet to a point where the sewage surface was more still.

d. Comparative figures of flow as measured by the ultrasonic equipment with those measured by other metering devices are not given for the demonstration sites described.

e. Total system cost for each site was about $15,000. Future simplifications of the ultrasonic circuitry made possible through more extensive use of integrated circuits have the promise of reducing this system cost by a factor of two or three.

BIOLOGICAL TREATMENT OF COMBINED SEWER OVERFLOW AT KENOSHA, WISCONSIN

Reference (85) describes the design, construction, operation and two year evaluation of a biological process used for the treatment of potential combined sewer overflow. A 76 MLD (20 MGD) modified contact stabilization process plant was constructed on the grounds of the city's existing 87 MLD (23 MGD) conventional activated sludge plant at a total cost of 1.1 million dollars.

"During 1970 while design and construction of the demonstration system facilities was occurring, a program to determine the quality of the combined sewer overflows in Kenosha was carried out. This included measurement of rainfall, combined sewer overflow quantity and quality, and influent quality to the WPCP (water pollution control plant) during rainfalls."

Flow measurement equipment was installed in the outfall lines of three overflows, known as the 57th Street, 59th Street, and 67th Street overflows. Depth recorders installed were operated on a differential pressure basis.

"Inert nitrogen gas was introduced into tubing which ran between the recorder and the bottom of the outfall sewer. As the flow (head) in the sewer increased, the nitrogen escaping from the end of the tubing in the sewer was decreased, proportional to the depth of flow, causing the pressure within the tube to increase. This increase in pressure was converted to depth readings and recorded on a circular chart. The chart was divided into 24 equal sections and driven by an 8 day clock."

Depth-discharge relationships were developed for the three overflow lines by means of dye tests. However, no details of the test procedures were given.

As a result of an unsuccessful attempt to correlate rainfall volumes with overflow volumes, it was disclosed that the overflow measuring devices were of questionable accuracy. In some cases, the volume of overflow measured exceeded the volume of rainfall over the combined sewer area. Apparently, the depth-discharge relationships were not accurate and so the overflow data were not used.

Measuring sites at the 57th Street and 59th Street overflows were abandoned in 1972. The depth recorder at the 67th Street site was moved upstream above the weir diverting flow to the interceptor sewer. The end of the bubble tube was placed just upstream from the overflow mechanism, and a formula for broad-crested weirs was used to convert level over the weir into flow rates and volumes. Flows computed in this manner were used to estimate the total volume of overflow to the demonstration treatment plant.

FLOW AUGMENTING EFFECTS OF ADDITIVES ON OPEN CHANNEL FLOWS

Reference (86) describes some laboratory experiments conducted to study the effects of polymer additives on open channel flows. Two sheet steel channels 18m (60 ft) long and painted initially with epoxy paint (n=0.009) and later with a sand and paint mixture (n=0.013) were used in the tests. One channel was rectangular with a bottom width of 15 cm (6 in.) and a side length of 15.2 cm (6 in.) while the other was trapezoidal with a bottom width of 12.7 cm (5 in.), a 60° interior angle, and a side length of 15.2 cm (6 in.). Slopes could be adjusted to 0, 1, 2, 3, and 4%.

A series of tests was conducted to determine the effects of a polymer additive on four types of flow measurement devices. A Parshall flume, 90° V-notch weir, and suppressed rectangular weir were adapted to the smooth-wall rectangular channel and tested at a 1% slope, while a Leopold-Lagco flume and a 90° V-notch weir were tested in the smooth-wall trapezoidal channel at a 2% slope. No sizes are given for any of the flow measurement devices, nor can they be estimated from a photograph in the report except to note that the crest height of the rectangular weir is low (perhaps 20% or less of the channel depth) as is that of the V-notch weir for use in the trapezoidal channel. Conversely, the V-notch in the weir used in the rectangular channel appears to "run out" at the top of the channel.

The general procedure followed was to calibrate each device in place using tap water, and then to inject the polymer to yield a predetermined concentration and develop a new calibration curve. Head was measured using a pointer gage "usually at the inlet to the device". A stop watch, 19ℓ (5 gal) bucket, and scale were used to determine flow rates under 570 ℓ/m (150 gpm) (where most of the data were taken), while an orifice meter was used for higher flow rates.

Calibration of all devices was affected by the addition of polymers. The Parshall flume was least affected, while the V-notch weir suffered a greater calibration curve shift (e.g., discharge could be understated by over 50% of all but the lower flows). The Leopold-Lagco flume and the rectangular weir ceased to be effected as flow measurement devices above a transition flow rate. The data are inconclusive, but indicate that polymer additives can affect primary flow measuring devices and point out the need for careful research in this area.

SURGE FACILITY FOR WET AND DRY WEATHER FLOW CONTROL

Reference (87) represents the culmination of a 3-year demonstration project which encompassed the design, construction, operation, testing and evaluation of a surge facility designed to provide flow equalization and some degree of treatment to all storm flows and to provide rate control of all wet weather and dry weather wastewater flows to interceptor sewers.

The principal elements of the facility are a sedimentation-equalization basin, a clarifier, a storage pond, a chlorine contact basin, and a sludge digester. Flow and hydraulic measurements include: (a) influent to the sedimentation-equalization basin; (b) underflow from the sedimentation-equalization basin to the clarifier and the storage pond; (c) overflow from the sedimentation-equalization basin directly to the storage pond; (d) water surface elevation of the sedimentation-equalization basin; and (e) effluent to the chlorine contact basin and the receiving stream.

The influent metering structure is a Parshall flume with a 0.30m (1 ft) throat width having a maximum capacity of approximately 30 MLD (8 MGD). The influent flow transmitter to the control building can be used to control a flow proportional sampler of the influent.

Underflow from the sedimentation-equalization basin is measured with a 15.2 cm (6 in.) magnetic flowmeter. The underflow can be set at any desired rate up to 8.7 MLD (2.3 MGD).

Overflows from the basin are measured by four sharp-crested rectangular weirs, totaling 2.54m (100 in.). Head on the weirs, and the water surface fluctuations in the sedimentation-equalization basin, are monitored with a Stevens Type F water-stage recorder. Time gears were selected to give an 8-day chart, and stage gears were selected to give an indication of 0.06m/cm (0.5 ft/in.) of chart or 0.012m/cm (0.1 ft/in.) of chart, depending on the depth variation expected during any particular testing period.

Effluent from the facility is measured with a combination of a 15.2 cm (6 in.) Parshall flume and a 137 cm (54 in.) sharp-crested rectangular weir. The two flow measuring devices are set to give a combined capacity of 22.7 MLD (6 MGD). The effluent flow transmitter can be used to control a flow proportional sampler of the effluent.

No discussion of problems with flow measurement equipment is given in the report. Flow data presented in the report appear to be complete and accurate. *"With the influent and underflow metered and the water surface monitored continuously, it was relatively easy to produce a uniform underflow rate during normal dry weather flow periods while maintaining a desired variation in water surface and preventing overflow to the storage pond."*

A PORTABLE DEVICE FOR MEASURING WASTEWATER FLOW IN SEWERS

Reference (88) is a final report of a program to develop a portable device capable of measuring wastewater flow in sewers. The work consisted of: an investigation of the theoretical approach to be used; laboratory investigations and experiments to develop design criteria; design and fabrication of two prototype units; and field testing and evaluation of these units.

Methods investigated for determination of velocity in the sewer, prior to selection of the heat pulse method for development, are as follows:

a. <u>Capacitance - Air Bubble Method</u>

This method depends upon the electrical capacitance of the wastewater flow cross-section and the effect on this capacitance of the displacement of air bubble tracers as they rise and are swept downstream past a capacitor plate. This approach failed due to "background noise" and, at low velocities, due to too rapid rise of bubbles in the flowing water.

b. <u>Inductive Method</u>

"Utilizes a drive coil external to the pipe to create an audio frequency magnetic field. The magnetic field, in turn, induces an eddy current in any nearby conductor, such as the water in the pipe. This eddy current can be detected by sensitive pickup coils located near the pipe invert. If the water is moving, the signal detected will be out of phase with the stronger signal resulting from direct coupling of the drive and pickup coils, the amount of this phase shift being correlated with effective velocity."

Failure of this method was attributed largely to the extreme smallness of the signal to be detected.

c. <u>Electromagnetic Flowmeter</u>

This included the rather commonly used electromagnetic flowmeter approach for measurement in a full pipe. However, it was decided that bulkiness of the equipment precluded its use for a portable, easily installed instrument.

d. <u>Electric Current Method</u>

A voltage was applied across a dynamic test section, between two electrodes in direct contact with the water. A change in d-c voltage was observed as velocity changed. An increase in current was observed as velocity decreased, with the filled cross-section remaining the same. Problems encountered were random changes due to d-c signal "drift", and plating by the direct current on the exposed electrodes.

The method finally selected for more detailed investigation involved the timing of a heat pulse as it traveled down the pipe. Thermocouples were used to sense the travel of heat induced by the injection of steam into the flowing water. Measurement of the cross-sectional area of flow was done by the use of capacitor plates to sense the change in water level in the sewer pipe.

"Two prototype gages were fabricated. The overall accuracy of the final prototype was, at best, ±15 percent."

JOINT CONSTRUCTION SEDIMENT CONTROL PROJECT

Reference (89) describes a demonstration project which consists of: (a) the implementation, demonstration, and evaluation of erosion control practices; (b) the construction, operation, and demonstration of the use of a stormwater retention pond for the control of stormwater pollution; and (c) the construction, operation, and maintenance of methods for handling, drying, conditioning, and disposing of sediment. As part of the project, a gaging and sampling program was conducted to determine the effects of urbanization on storm runoff and water quality of natural areas.

Four automatic flow gaging and water sampling stations were installed on small streams of the study area. Two of the stations were installed adjacent to each other on streams just upstream from their junction. One of these streams drains an experimental watershed and the other drains an adjacent reference watershed. Two other gaging and sampling stations were established immediately upstream and immediately downstream from a 1.6 Hectare (4 acre) pond.

At three of the gaging sites, precalibrated, broad-crested, V-notch weirs developed and tested by the U.S. Department of Agriculture were installed. At two sites, the concrete weir caps have 2:1 side slopes; at the third site, side slopes of the weir cap are at 3:1. At the gaging site downstream from the four-acre pond, a sharp-crested, compound, 90°, V-notch and rectangular weir was installed.

A Stevens Duplex Water-Level Recorder Type 2A35 was used to simultaneously record water levels at the two adjacent stream sites. A Stevens Type A35 water level recorder was used upstream from the pond, and a Belfort liquid level recorder was used at the downstream site.

A Gurley pygmy current meter was available to perform additional stream gaging, but was used primarily to check the calibration of the permanently installed weirs.

The weirs and level recording devices used are said to "have proven to be accurate, reliable, and easy to maintain". However, it was found necessary to clean out sediment above the three U.S.D.A. weirs "--*after each storm and sometimes under base flow conditions to maintain the calibration and accuracy of the weirs*". No cleanout was required at the compound weir downstream from the pond. Because of the reported accumulation of sediment found after each storm, accuracy of runoff records at the three sites during periods of storm runoff may be questioned. An unknown pattern of alternate sediment accumulation and flushing during the storm runoff period could occur. Calibration may have been incorrect during the falling limb of the hydrograph, when sediment was accumulating.

COMBINED SEWER OVERFLOW ABATEMENT PLAN, DES MOINES, IOWA

Reference (90) is a report on a project designed to provide engineering information regarding the volume, character, and impact of combined sewer overflows and urban stormwater discharges from a typical midwestern metropolitan area. The project includes an engineering evaluation of solutions to the problem, including combined sewer separation and investigation of facilities for the treatment of both combined sewer overflows and stormwater discharges.

Several different types of equipment and methods were used to measure flows and to provide secondary stage measurements. Weirs of the 90° V-Notch type and rectangular weirs, both suppressed and contracted, were used. At sites with larger volumes of flow, a stage-discharge relationship was determined using current meters. Natural controls of a permanent nature were found at these sites. The Manning formula, with water-surface slope and an "n" value of 0.018, was used to determine discharge in one conduit. The main outfall of the wastewater treatment plant was measured with a raw sewage flow totalizer of an undisclosed type. Stick gages painted with water soluble paint were used to detect overflow occurrences. Both Stevens Type F Recorder, Model 68, and project designed and fabricated compressed-air bubbler recorders were used to record water levels.

Dry-weather sanitary sewer flows were measured in eight sewers and in the main outfall of the wastewater treatment plant. Weirs were used in all sewers and float recorders were used in seven of them. A bubbler recorder was used in the eighth. No problems in measuring dry-weather flows with this equipment were reported, although no check on accuracy is available.

Because of the extended period of high river stage, flow measurements during wet weather were generally not obtained in the sewers or overflow points. During this period, most of the flow measuring sites were either submerged or at least intermittently affected by high water. Overflows at one point were estimated by use of the Manning formula, and at another point by use of a current meter.

Stormwater runoff was measured at four gaging sites on storm sewers. At three sites, flow was measured by means of weirs and bubbler recorders. During periods of high river stage, one of these sites was submerged or affected by backwater, when no record was obtained. Runoff at the fourth site was determined from a stage-discharge relationship established by current meter measurements. A concrete sewer line crossing the channel provided a permanent type control. The rating curve was extended an undisclosed amount above the highest current meter measurement.

COMPUTER MANAGEMENT OF A COMBINED SEWER SYSTEM

Reference (91) describes a computer-controlled "total systems management" complex, which affects much of the combined sewer system of Seattle, Washington. Computer-augmented treatment and disposal (CATAD) takes advantage of storage in the sewers to limit overflows, and selects overflow points based on water quality data.

Development of the control system included the installation of 36 remote sensor stations and the construction of 15 gate-driven regulator stations. Work continues on a fully automatic optimizing model to program decisions so the system can maintain an 80% overflow reduction.

"Water levels at many locations are probably the most important single category of information required to calculate flows and trigger certain types of alarms. By incorporating Manning's equations, various orifice and weir formulae and pump efficiency curves, it is possible to calculate flow at almost any location in the system. The computer checks water elevations with reference to overflow weirs to generate prealarms before overflows take place and/or actual alarms after the overflow has begun. Monitoring, control and modeling of the entire system depends upon flow information from many locations, some of which cannot be obtained from water level measurements alone. In the CATAD system, these additional on-line flow measuring techniques are employed:

1. *Flow measuring weirs are installed at various locations.*

2. *A calibrated propeller type flowmeter is monitored at the West Point treatment plant site.*

3. *Force main pressure calibration methods are used at pump stations where there is sufficient friction head loss to calibrate the force main at various flow ranges."*

In addition, more than 100 Palmer-Bowlus flumes are installed in manhole locations. A computer program has been applied for rating these measuring flumes, using data including sewer diameter, shelf height, flume side slopes, and elevation of vertical side slopes.

Level sensors used in the system are generally pneumatic bubblers with back pressure read by a differential pressure transmitter. The accuracy of measurements was checked by direct level measurements to bring instrument calibration of the various stations into agreement with the system datum. It was determined that the overall accuracy probably approaches about 2% of the full scale measurement.

Project experience demonstrated that manufacturer's pump unit performance curves may be used to calculate reliable flows provided that critical analog sensors, particularly pump speed sensors, are reliable.

Because flows calculated using performance curves had been considered dubious, force main pressure sensors were installed at many pump stations to provide alternative means of calculating station discharge. As a result of checking the pressure gages using the salt velocity method, it was found that flows thus calculated are not entirely reliable due to rapid fluctuation of analog pressure values.

Deficiencies in the flow calculation procedures for regulator stations were revealed. No allowance had been made for the effect of interceptor backwater affecting the tailwater at a regulator gate and no transition had been provided between fully-submerged and free discharge conditions. A backwater allowance was added, and a method of calculating the degree of gate submergence was developed.

CHARACTERIZATION AND TREATMENT OF URBAN LAND RUNOFF

Reference (92) describes a project to characterize the runoff from a 4.3 sq km (1.67 sq mi) urban watershed in Durham, North Carolina with respect to annual pollutant yield. The U.S. Geological Survey operates a continuous stage recorder and two digital punch tape precipitation recorders within the basin. Stream-flow control is provided by a shallow V-notch weir located on Third Fork Creek some 21m (70 ft) downstream from a bridge culvert and 11.3 km (7 mi) upstream from the mouth of Third Fork Creek. Water quality samples were taken from the center of the stream approximately 1.5m (5 ft) below the weir. Thus, rainfall, runoff, and water quality data were gathered for the basin and analyzed. The USEPA Storm Water Management Model (SWMM) was also evaluated with respect to actual conditions as measured in the field and "was judged to predict peak hydrograph flows and total hydrograph volumes with reasonable accuracy; however it was not judged effective for predicting pollutant concentrations".

In order to assess the impact of varying types of land use within the basin on urban runoff quality, 5 storms were manually sampled at subbasin discharge locations. A control section, usually a pipe or box culvert, was utilized with Manning's equation to arrive at stage-discharge relationships for each basin sampled. The stage was manually read when a sample was taken. No accuracy estimates are available.

OTHER USEPA PROJECTS

Among USEPA projects for which final reports are not available is a project (EPA S-802400) to demonstrate disinfection and flash treatment of combined sewer overflows at Syracuse, New York. Disinfection is applied for one minute after solids removal by high rate screening. Flow of combined sewage is measured from three pumping stations to installations of fine mesh and micro screens. Also, flow in solids return lines from the screens is measured and used to control backwash of the screens. Flow from the three pumping stations is measured by Brooks electromagnetic flowmeters. Solids return from the screens is measured with a weir and a Badger Meter, Inc. float level indicator. Problems were experienced in printed circuits of the signal converters used with the Brooks electromagnetic flowmeters. Initially, other problems necessitated that adjustments be made by Brooks' representatives.

A USEPA grant project (EPA Y-005141) with the Monroe County Pure Waters Authority is to develop a master plan for treatment, conveyance, or holding alternatives to effectively handle the combined sewer overflows from the Rochester, New York, sewer system. Flow quantity and quality data collected for the project are to be used in calibrating the USEPA Stormwater Management Model. The master plan is to be so developed to provide guidelines for use in preparing such plans for other cities. Measurements of thirteen combined sewer overflows, and at four locations in interceptor sewers, are being made. At five of these locations, Badger Meter, Inc. ultrasonic flowmeters are used in conjunction with Badger ultrasonic water surface level indicators. At eleven locations, Badger ultrasonic level indicators only are used to record head over weirs or to provide data for use with the Manning formula. A Fischer-Porter bubbler gage above a combination weir-orifice is used for flow measurement at one site. All data are transmitted to a central computer. Redesign of the ultrasonic head probes was found necessary due to echoing in the sewers, but they are now reported to be operating satisfactorily. Problems of interfacing with the computer were experienced, but very good operation has been obtained after six to eight months' experience.

A project (EPA No. 11024 FIU) was for the design, fabrication, and testing of a prototype 30.5 cm (12 in.) vibratory sewer flowmeter. The flowmeter to be developed was to operate on the principle that the reaction of flowing material to a mechanical vibration applied to the stream boundary in a direction transverse to the direction of flow is a direct measure of mass flow rate. The essential elements are an actuator to impart a vibratory force or motion to the flowing material and a sensor to measure the reaction. This type of device has been used successfully for measuring very small flows, but the mechanical problems with equipment for use in a sewer were not successfully solved with the time and funds available.

A project (Contract No. EPA 68-03-0341) with Cushing Engineering is for the "Development of an Electromagnetic Flowmeter for Combined Sewers", which may result in a device capable of measuring flow under open-channel conditions as well as in a full, pressurized pipe is in progress. The open channel electromagnetic flowmeter will have a primary unit or transducer (i.e., the portion through which the fluid flows) that is not considered to be appreciably more complicated than the conventional instrument; however, it does require more sophistication in its secondary unit (i.e., in its signal conditioning unit). The primary unit is very similar to standard electromagnetic flowmeters except that in this case a manifold of detection electrodes (as opposed to a single pair) are employed so that measurement can be made throughout the varying depth of the liquid. The outputs of the detection electrodes are fed into an adder network which totals the voltage sensed in accordance with height of flow.

The EPA has contracted (Contract No. 68-03-2121) with Grumman Ecosystems Corporation for the development of a new, non-intrusive, low cost, passive measurement system capable of monitoring flow in storm, combined, and sanitary sewers. The system's concept involves a proprietary technique of utilizing the sound emission resulting from the interaction of fluid flow with a discontinuity of a solid surface. In the application to sewer flow, a discontinuity is any inherent change in the sewer cross-section, slope, or direction that can significantly affect the flow area or direction. Laboratory investigations directed to optimize system design details for sewer installations, and analyses which will relate theory and test data to measurement system design objectives and applications are currently underway. By proper signal processing, the acoustic emission flowmeter can be made to differentiate between sound that is indicative of and generated by the quantity of flow and noise caused by noncorrelatable secondary flow processes and general background noise. Several factors may affect sound production and transmission in wastes such as a suspension of bubbles, temperature gradients and stratification, etc. These areas must be investigated and either avoided or compensated for by selection of sound pickup locations.

PROJECTS BY OTHER FEDERAL AGENCIES

Federal agencies which have been active in development of improved flow measurmenet equipment and methods, with a brief description of their work, are given below. Other Federal agencies have carried on similar useful projects in past years, but have been omitted where information on possible recent work was not available. The information presented here was obtained either by telephone or personal interview.

Agricultural Research Service

Work on improved designs of trapezoidal-type measuring flumes to overcome sediment problems is being conducted in Phoenix, Arizona.

Bureau of Reclamation

Radioisotope Flow Measurement - Equipment and methods for measuring flows in canals, pipelines, and turbines with radioisotope tracers have been developed by the Bureau during the past ten years. Public resistance to injection of radioisotopes into water supplies has minimized their use.

Ultrasonic Flowmeter - Ultrasonic flowmeter equipment furnished by the Badger Meter Company was tested in a 61 cm (24 in.) diameter pipeline and in a 76 cm (30 in.) wide channel. A measurement accuracy of ±2% was obtained in the pipeline. A significant conclusion was that the flowmeter transducers should be installed in direct contact with the water rather than on the outside of the pipe.

Rotameter-type Flowmeter - Combined rotameter-type flowmeter and flow controllers of 25.4, 30.5, and 35.6 cm (10, 12, and 14 in.) sizes were studied in the laboratory. These devices totalize flow, indicate flow rate, control flow to preset rates, and provide shutoff. Further field operation and experience is necessary to fully evaluate the devices.

The Bureau of Reclamation conducts a continuing research program in the fields of water system automation and flow control. Studies in the use of electromagnetic and ultrasonic methods of flow control are in progress.

Corps of Engineers

Recently, Westinghouse ultrasonic flow measurement equipment has been installed on the Columbia River to provide improved information on powerplant operation. This work was performed by the personnel of the Portland District in cooperation with the U.S. Geological Survey.

Satellite transmission of data is being investigated in the New England Division. Telemark data transmission systems are being discontinued and are being replaced by radio transmission. It is expected that data transmission in the future will be tied to the National Oceanic and Atmospheric Administration System of Automation of Field Operation and Services.

Geological Survey

The Water Resources Division of the Geological Survey maintains a continuing program to improve water measurement devices and procedures.

Recently, a flow measurement device for measurement of storm runoff in sewers has been developed, and a number of them are being installed in several sewered catchment basins. The device functions within the sewer under both open-channel and pressure flow conditions, and is said to cause only an insignificant amount of head loss. Under open-channel conditions, the meter functions as a venturi flume. For pressure flows, the device operates like a modified venturi meter. This flowmeter is very similar to that developed by Dr. Harry G. Wenzel of the University of Illinois. A significant difference is that the upper position of the pipe is unconstricted, reducing discontinuity between the open-channel flow rating and the pressure flow rating.

PROJECTS OUTSIDE THE UNITED STATES

The reader is cautioned not to assume that all the flow measurement research today is being conducted in the United States. Most industrialized countries are active in this area, and new or improved flow measuring devices and techniques are being reported by foreign investigators. Coverage of all foreign research simply was outside the scope of the present effort, but would be a fit subject for a future study.

However, mention will be made of one Canadian development recently reported by Marsalek (93) because of its promise for application at sites troubled by surcharging. It is essentially a flume-dilution combination for sewer flow measurement. The equipment involved is all portable and suitable for manhole operation. At the primary wastewater characterization site a Palmer-Bowlus type flume, a water level recorder (a capacitance-type probe was used in this case), and an automatic discrete sampler were installed. At a manhole sufficiently upstream to assure that complete mixing would occur a tracer supply and metering feed pump were installed.

Under ordinary (open channel) flow conditions only the equipment at the primary site is in operation. When the water level, as measured by the capacitance probe, reached a pre-determined value indicating that submersion effects would be seriously degrading discharge values as measured by the flume, an alarm relay activates the tracer feeding pump at the upstream site. The chemical dilution technique is applied for the "high flow" periods by analyzing the samples collected by the automatic sampler to determine tracer concentrations.

SECTION IX

FUTURE AREAS OF RESEARCH AND DEVELOPMENT

Although the general state of the art of flow measurement has come a long way since the days of Sextus Julius Frontinus (e.g., we can accurately measure cryogenic flows, liquid sodium flows, mixed gas and vapor flows, etc.), the most common flow measurement devices and techniques used in sanitary engineering are but modest improvements upon nineteenth century (or earlier) developments. This is not surprising in view of the National priorities that have been given to space and nuclear energy programs, and the concomitant application of resources to the development of technologies directed toward the solution of problems in these areas. As was pointed out earlier in this report, we are now becoming more and more aware of the importance of accurate sewer flow measurement and, in recent times, have begun to devote increasing attention to it. Storm and combined sewer flows, as noted, are among the most difficult to measure well, and much remains to be done before we can claim that the state of the art, as being practiced, is equal to the task.

As a result of the activities conducted during the course of this study, including the review of older research and development projects as well as current and on-going ones, it appears that there are several promising research areas that could produce improvements within a short-term time frame. They have been divided into three categories: general research, which is more basic or fundamental and applicable to a number of different classes of flowmeters; applications research, which deals with the engineering required to adopt already-developed building blocks into flow measurement systems suitable for the storm and combined sewer application; and demonstration research, which is the actual field use and evaluation of existing equipment that either has not been tried before or about which there is presently insufficient information.

Several promising activities within each area will be discussed. No attempt to be exhaustive or all-inclusive has been made. Rather, the activities suggested have been selected because of a critical need, the promise of a high probability of positive results, and/or the immediacy with which results could be obtained. The selections are necessarily somewhat subjective, and doubtless some readers will be concerned that one of their "pet" areas has not been included. The writers can only hope that any such criticism will be tempered by the realization that a complete coverage of all possible contributory research could more than double the size of this already somewhat lengthy report.

Two general recommendations will be treated outside the just mentioned categories because they tend to overlap and are a bit more policy/priority than specific task oriented. First, there is a need for a facility where controlled flows of wastewater can be maintained so that various alternative devices and techniques can be tested in a side-by-side fashion. It is imperative that this facility be capable of operation with actual sewage as well as water in view of possible interference effects to some flow measurement equipment that might be caused by the former. A facility was developed as a part of a USEPA funded study and evaluation of a periodic flushing system for combined sewer cleansing by FMC Corporation. It has variable slope test sewers of 30.5 and 45.7 cm (12 and 18 in.) diameters and can utilize actual sewage. It is recommended that this facility be evaluated for the purpose of side-by-side flow measurement device testing and so utilized if indicated.

The second general recommendation arises from the very nature of the storm and combined sewer application itself. It is strongly recommended that priority be given to the development of portable flow measurement devices that could be used for overall survey work, for gathering field data for use in the development of computer stormwater management models, for conducting infiltration/inflow studies, and the like. The importance of a portable flowmeter for each of the cited uses is well known and will not be belabored here. The problem is that the need is still largely un-met. Of the following research recommendations, it is recommended that those activities that will be contributory to the development of portable devices be undertaken first.

GENERAL RESEARCH

Much remains to be learned about the physics of complex flows such as stormwater or combined sewage. They are multi-phase mixtures containing solids, liquids, and gases and are unstable, with constituents going into and out of solution as the flow progresses. When combined with the problems introduced by nonuniform, unsteady turbulent flow, the research possibilities are mind-boggling. Only three, which the writers feel are both of immediate concern and reasonable tractibility, will be discussed.

Effects of Entrained Air and Solids

Entrained air and solids in the flow can have an effect on several different types of flow-measuring equipment. One of the most recent and promising methods of flow measurement utilizes ultrasonic equipment, which is known to be adversely affected by these elements. Experience to date has shown that the presence of heavily concentrated air bubbles in the flow interferes with operation of ultrasonic flowmetering equipment. This is true even when the bubbles are so small that they are hardly visible. The only solution thus far proposed is to install the flowmeter where such bubbles do not form; that is, to avoid locations below drops, chutes, and hydraulic machinery which cause air entrainment in the flow. A method for overcoming this restriction of meter applicability is needed, and should be investigated further.

A similar interference by solids suspended in the flow has been noted. Although methods for overcoming the effects of larger, more widely spaced suspended solids have been developed, fine silts remain a problem. Further study to better understand and overcome such effects on ultrasonic velocity measuring devices is recommended.

Polymer Effects

The introduction of selected polymers to pipe flows has been demonstrated to significantly increase the pipe carrying capacity. Flow increases of as much as 240% at a constant head have been achieved. Field tests reported by The Western Company (94) on a 61 cm (24 in.) line demonstrated that surcharges of greater than 1.8m (6 ft) could be eliminated by polymer additives. Similarly, the capacity of open channels has been increased through use of friction-reducing additives, although to a lesser extent, as noted by Derick and Logie (86).

The addition of polymers to the flow can have a significant effect on the calibration of certain types of flow measuring equipment, as also reported by Derick and Logie (86). Although they only tested flumes and weirs, effects could be even more pronounced in those devices that presuppose velocity distributions in the flow. Ultrasonic flowmeters are a particular case in point. For example, little is known about the effect of changing the viscosity of the water on the character of the ultrasonic pulse through the water, or about the reduction of turbulence causing a change in velocity distribution in the cross-section. Because of the potential for increased use of polymers for flow control, study of their effects, especially on ultrasonic flow measurement equipment, is recommended.

Velocity Distribution

Although a significant effort has been made to define the relationship between average velocity along a horizontal chord or traverse, elevation of the chord or traverse, and the average velocity in the cross-section, much more work would be helpful in reducing the cost of flow measurements. Theoretical computations and laboratory and field observations have been made in the past, but a consolidation of known information, reinforced with selected additional data, would be quite useful, since many of the flow measuring devices infer average velocity from point or chordal measurements. This is particularly true with respect to ultrasonic flow measurements, where the average velocity along a chord or traverse between two meter probes is measured. Further knowledge of these relationships would also be useful with other flow measurement devices where flow is computed from the product of average velocity in the cross-section and the cross-sectional area.

APPLICATIONS RESEARCH

The state of the art and technologies are now at hand to allow the development, based on already established building blocks, of improved flow measuring devices for application to the storm and combined sewer problem. A few examples will be discussed.

Automated Dye-Dilution Devices

As discussed in Section VI, dilution techniques are very promising for application to the measurement of storm or combined sewer flows, especially in view of the new fluorescent dyes now available. Suitable equipment for either controlled-rate or slug injection of dye solutions is available. Automatic sampling equipment to allow reliable gathering of representative samples and fluorometers for automatically measuring dye concentrations are also available. There has even been work done on laser stimulation of fluorescence which could allow remote observation of dye concentrations without direct contact with the flow. Present integrated circuit technology would allow automatic conversion of dye concentrations to flow rates, in digital form, for indicating and recording and transmitting to central locations. It is even possible to develop a portable, battery-powered version that could be used for field calibration of existing flow measurement devices. It is recommended that a project to integrate these building blocks into an automatic flow measurement device be established, with emphasis on portability.

Portable Ultrasonic Devices

Sufficient field experience is now available to demonstrate the utility of ultrasonic equipment for the measurement of sewage flow, including stormwater and combined sewage. Development of portable equipment could expand the usefulness of this kind of flow measurement device to measurements of the miscellaneous type, such as in infiltration studies, to check the effluent from industrial plants, and for many other purposes.

Basically, ultrasonic flow measurement equipment is adaptable to compact packaging, as no large, heavy parts are required, even for measurements of large flows. Three separate packages might be developed - a level gage, several sets of meter probes, and associated electronic instrumentation. Provision should be made for installing the probes either inside or outside of closed conduits. Again, the fundamental building blocks are at hand, and it is recommended that such a project be initiated as soon as possible.

New Flumes

As noted in Section VI, there has been extensive research work performed on a variety of new flume configurations, with resulting designs that offer wider ranges, greater self-scouring characteristics, better submerged performance capabilities, etc., as compared to the more traditional designs, especially the Parshall flume. It is recommended that a project be established to consolidate the existing information on these efforts and, based upon this, to develop a flume possessing the most advantageous attributes in light of present day technologies and the storm and combined sewer application. For example, it might happen that a trapezoidal cutthroat flume with an automatic, electronic dual head comparison (Hb/Ha) and critical/submerged/pressurized flow algorithm shift integrated circuit card would offer great promise. Such a design is totally within the present state of the art and could be effected at a reasonable cost.

Ultrasonic Level Gages

As secondary elements in flow measurement devices, ultrasonic level gages show considerable promise for the storm and combined sewer application. They obviate the self-cleaning requirements of many secondary elements, offering the advantage of no requirement for contact with the flow stream whatsoever. Their use has been fraught with difficulty, however, especially in settings such as a manhole application. The problems, from discussions with various field and applications engineers, would appear to stem mostly from spurious or false signal returns due to echoing from the installation structure. The problem has been encountered in many applications, e.g., the Rochester project, and has been independently solved (or apparently so) almost as many times. For example, the USEPA National Field Investigation Center, Cincinnati, has experienced such problems with different makes of equipment and has developed an inexpensive modification that apparently corrects the problem. It is recommended that a project to review the history of such experiences, including problem and solution descriptions, be prepared and procedures developed for the use of ultrasonic level gages in such applications.

DEMONSTRATION RESEARCH

There are several flow measuring devices, either presently available or virtually ready to be introduced, that offer considerable promise in the storm and combined sewer application. However, information about their use in such a setting is lacking, but could be gained from testing in a suitable facility as discussed earlier or from other field use such as a demonstration as an adjunct to an on-going project; thus, definite recommendations as to their suitability or fitness as storm or combined sewer flow measurement devices can be made. Some of these will be briefly discussed.

Venturi Meter/Flume

These flow measuring devices are designed to operate under both open-channel flow and full-conduit flow under pressure. Under open-channel conditions, the meters act as supercritical flumes, but when completely filled and under pressure, they behave more like modified venturi meters. For open-channel flow, only the depth at a single (usually upstream) measuring section is required. When the pipe is flowing full, and is under pressure, the flow is a function of the difference in the upstream head and the head at, say, the meter throat or an exit head. Two such devices have been recently developed - one by Dr. Harry G. Wenzel, Jr. at the University of Illinois, and one by George F. Smoot of the U.S. Geological Survey.

The 20.3 cm (8 in.) diameter test meter designed by Dr. Wenzel has been sufficiently laboratory tested, but has not undergone field experience to evaluate its self-cleaning characteristics and its hydraulic performance. It is recommended that a prototype meter of larger size, at least on a 61 cm (24 in.) diameter line, be tested in an actual combined sewer in line with an accurately calibrated meter of another type.

Several similar flumes designed by George F. Smoot for the U.S. Geological Survey have been installed in storm or combined sewers. However, there has not yet been sufficient field experience to allow adequate evaluation of them. It is recommended that a flume of this design be installed (preferably) in line with the meter designed by Dr. Wenzel and an accurately calibrated meter of another type for further evaluation.

Combination Thermal Flowmeter

Two thermal flow tube meters are manufactured by the Thermal Instrument Company, one for measurement of flow in pipes that are flowing full and another for flow measurement in partially filled pipe. Although discussed earlier, the principle of operation of these meters is described briefly as follows:

"A sensing element located on the outside of the flow tube is energized with a small amount of electrical energy (less than one watt). The heat conducted off this element, by the flow stream, is directly proportional to the mass flow rate of the fluid.

Additional sensing elements are located on the tube to compensate and correct for the effects of fluid and ambient temperature."

For measuring flow in partially filled conduits, a liquid level sensor is placed on the outside of the unobstructed pipe, in addition to the velocity measuring sensors.

Very little experience has been gained with this type of flowmeter in measurement of sewage. Meters are now in operation on 50.8 cm (20 in.) pipes carrying recycled pulp wastes. There is said to be no upper limit on the size or range of these meters.

Because of the obvious potential advantages of such nonobstructing meters, it is recommended that they be evaluated in a line of moderate size, but under conditions of both open-channel flow and full flow under pressure. The test meter would be placed in line with a flow measuring device of another type with proven accuracy.

Self-Calibrating Acoustic Level Gage

The "Aquarius" acoustic level gage described in Section VII offers many apparent advantages over more traditional ultrasonic level gages as a secondary element in a flow measurement system. These include: complete independence from all environmental effects; almost an order of magnitude greater accuracy than presently available; a low production cost; portability, which includes the promise of outstanding battery life (up to one year); and immediate computer compatibility, owing to its advanced, all-digital electronic design. At this time, however, the device is so new that virtually no data (outside the laboratory) are available to substantiate these promises in a field setting. It is recommended that one of these devices be procured and installed, at a site with a suitable primary device, alongside a proven head sensor in order to demonstrate its real capabilities in a field setting.

High Range Open Flow Nozzle

The H-series flumes (or open-channel flow nozzles), that were developed by the U.S. Department of Agriculture, hold considerable promise as primary devices for successfully measuring storm and combined sewer flows at many sites, as discussed in Section VI. In view of their low cost and very wide measurement range, it is recommended that a project be initiated to: (a) gather available information on the various flumes of this type and other open flow nozzle designs; (b) analyze this design; and (c) fabricate and test such a primary device.

SECTION X

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16. ABSTRACT

A brief review of the characteristics of storm and combined sewer flows is given, followed by a general discussion of the need for such flow measurement, the types of flow data required, and the time element in flow data. A discussion of desirable flow measuring equipment characteristics presents both equipment requirements as well as desirable features and includes an equipment evaluation sheet that can be used for a particular application. A compendium of over 70 different generic types of primary flow measurement devices, arranged according to the fundamental physical principles involved, is presented along with evaluations as to their suitability for measurement of storm or combined sewer flows. To illustrate the implementation of the physical principles, a number of commercially-available devices for flow measurement are briefly described. A review of project experience in flow measurement is presented along with a summary of current and on-going research efforts. Some thoughts on future areas of research and development are also given.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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